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Silverstein et al.

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(54) **DISPLAY APPARATUS USING LCD PANEL**

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5,918,961 A 7/1999 Ueda

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 136 days.

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Primary Examiner—Melissa J. Koval

(21) Appl. No.: **11/120,340**

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(22) Filed: **May 3, 2005**

(57) **ABSTRACT**

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G03B 21/20 (2006.01)
G02F 1/1335 (2006.01)

(52) **U.S. Cl.** **353/20**; 353/94; 353/102; 349/9

(58) **Field of Classification Search** 353/20, 353/94, 102; 349/9

See application file for complete search history.

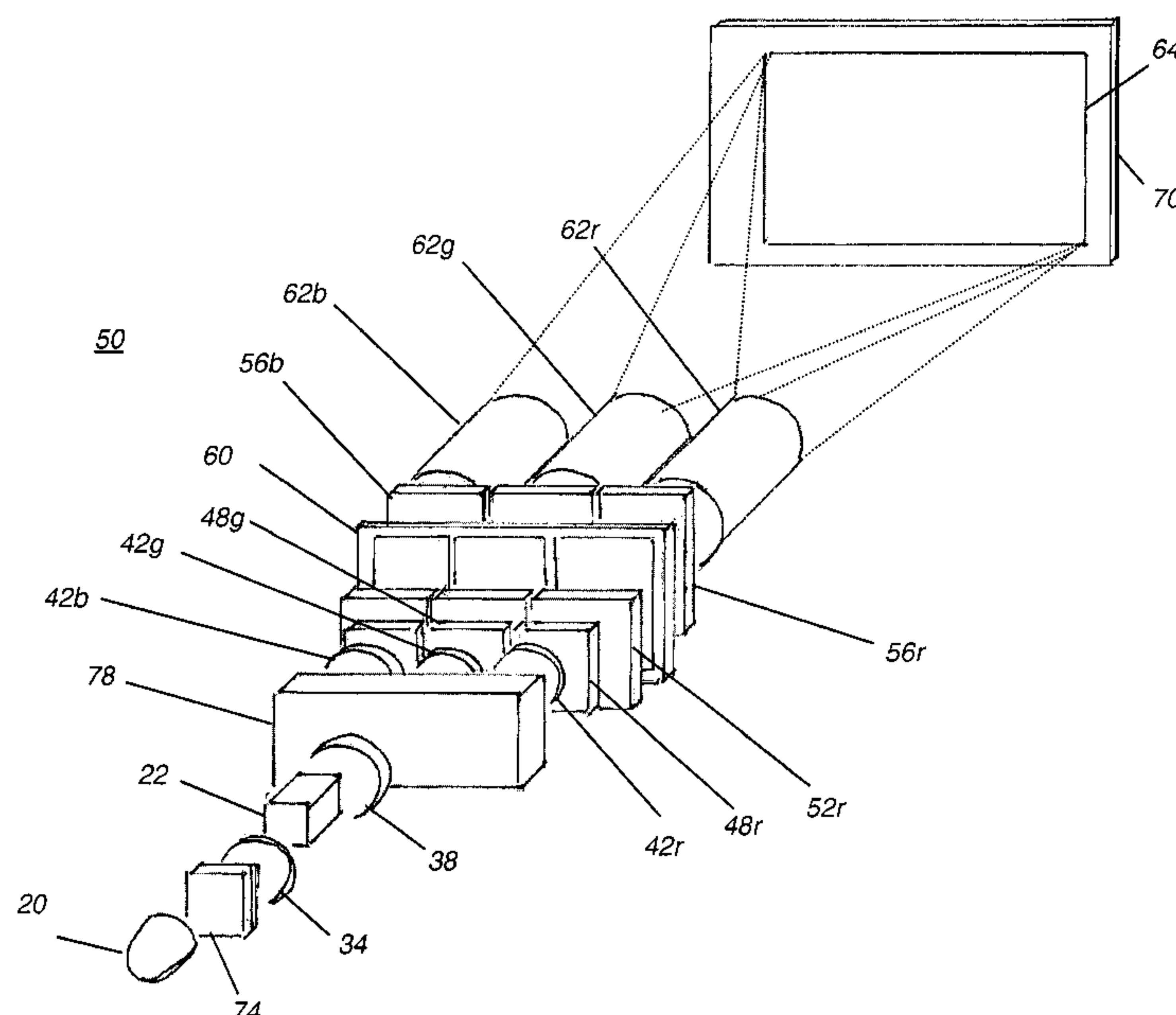
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A projection apparatus has an illumination section that provides first, second, and third light sources for providing first, second, and third illumination beams. First, second, and third component wavelength modulating sections modulate the corresponding illumination to provide first, second, or third modulated component wavelength beams respectively. Each component wavelength modulating section uses a portion of a monochrome transmissive liquid crystal modulator panel that has been segmented into at least a first, second, and third portion. A component wavelength polarizer in the path of the component wavelength illumination directs substantially polarized light to the corresponding portion of the monochrome transmissive liquid crystal modulator panel. An illumination path Fresnel lens focuses incident illumination from the component wavelength polarizer through the corresponding portion of the monochrome transmissive liquid crystal modulator panel. An analyzer conditions the polarization of the modulated component wavelength beam. A lens forms an image for projection onto a surface.

33 Claims, 17 Drawing Sheets



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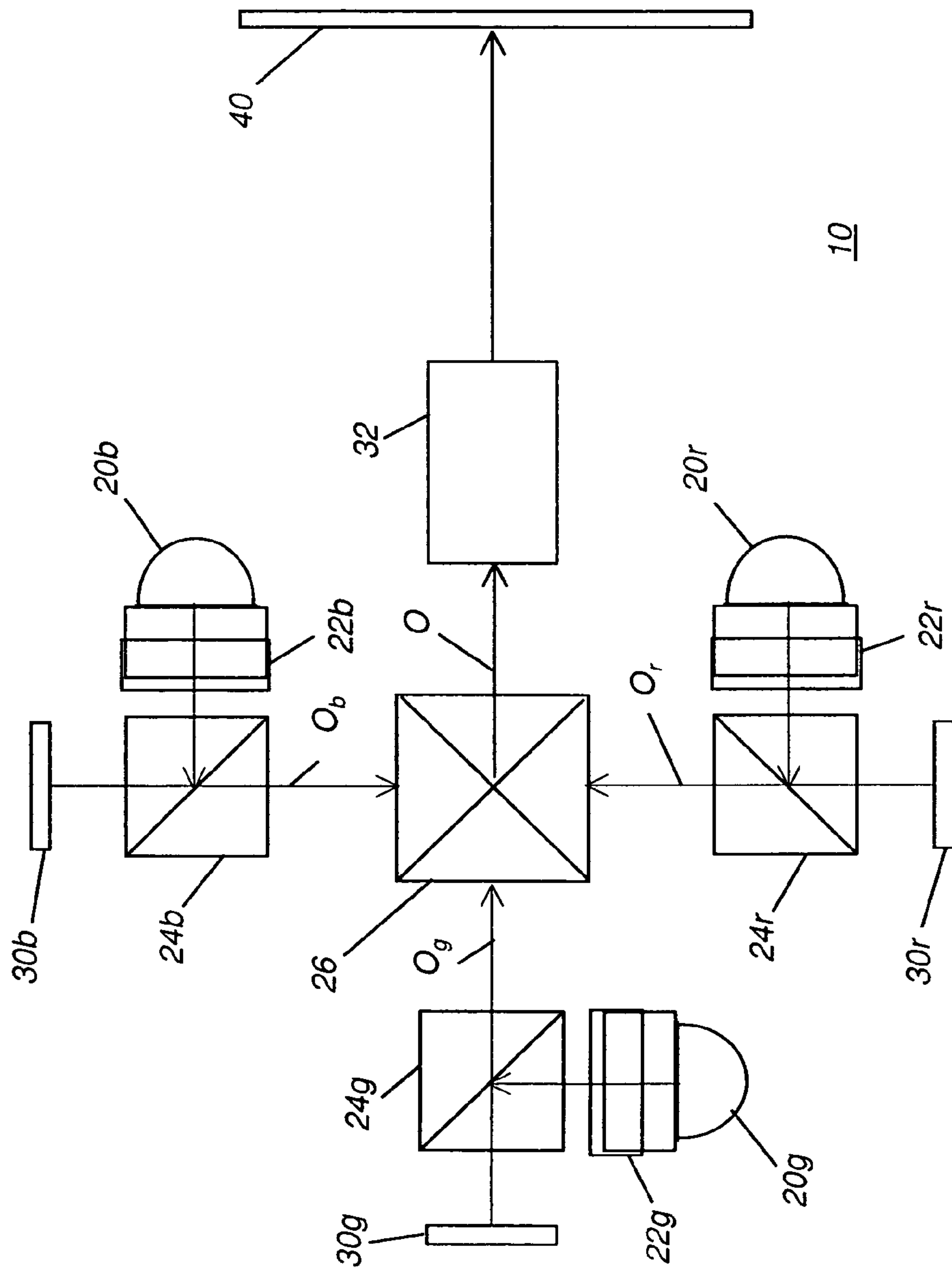


FIG. 1

PRIOR ART

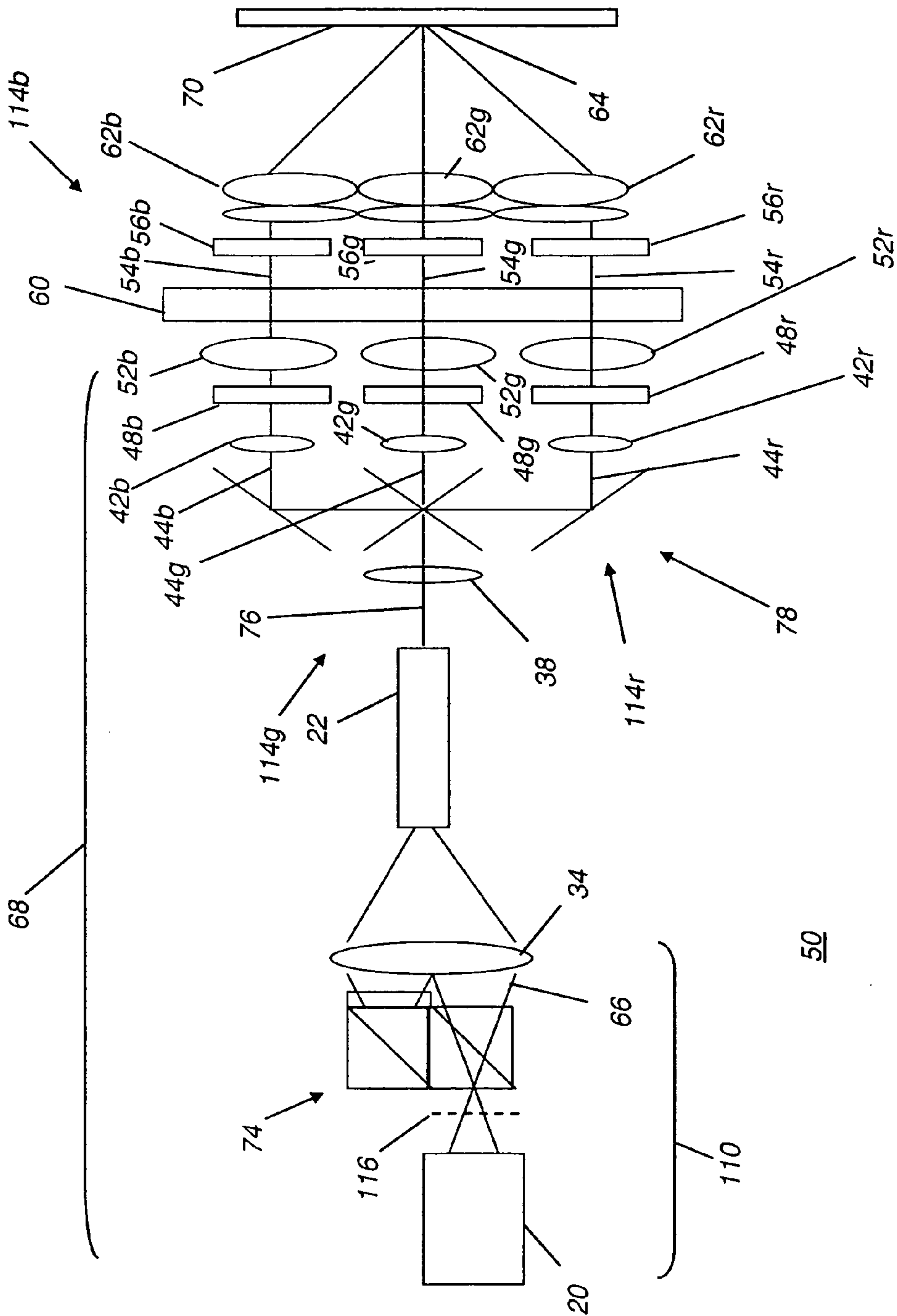


FIG. 2

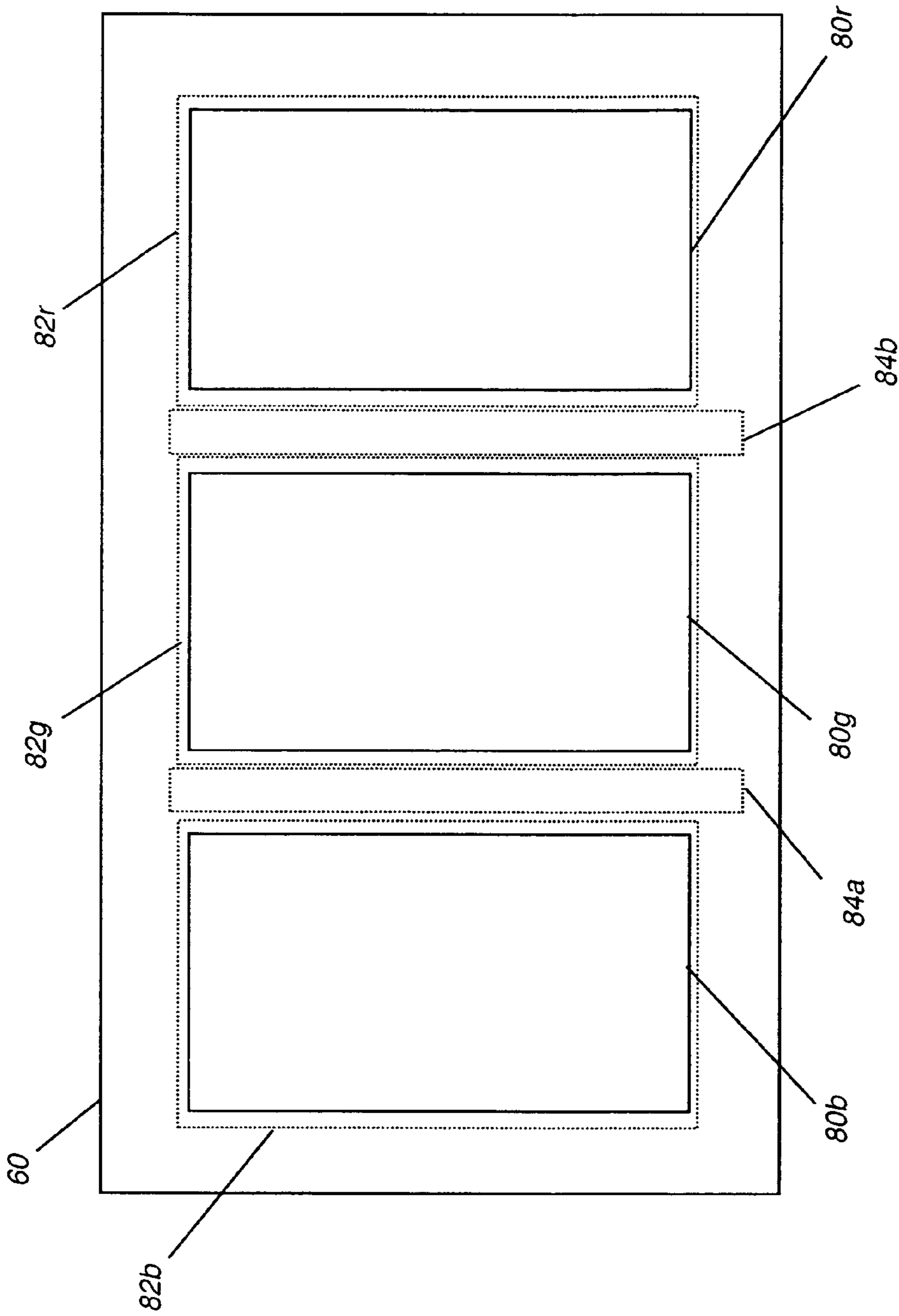


FIG. 3

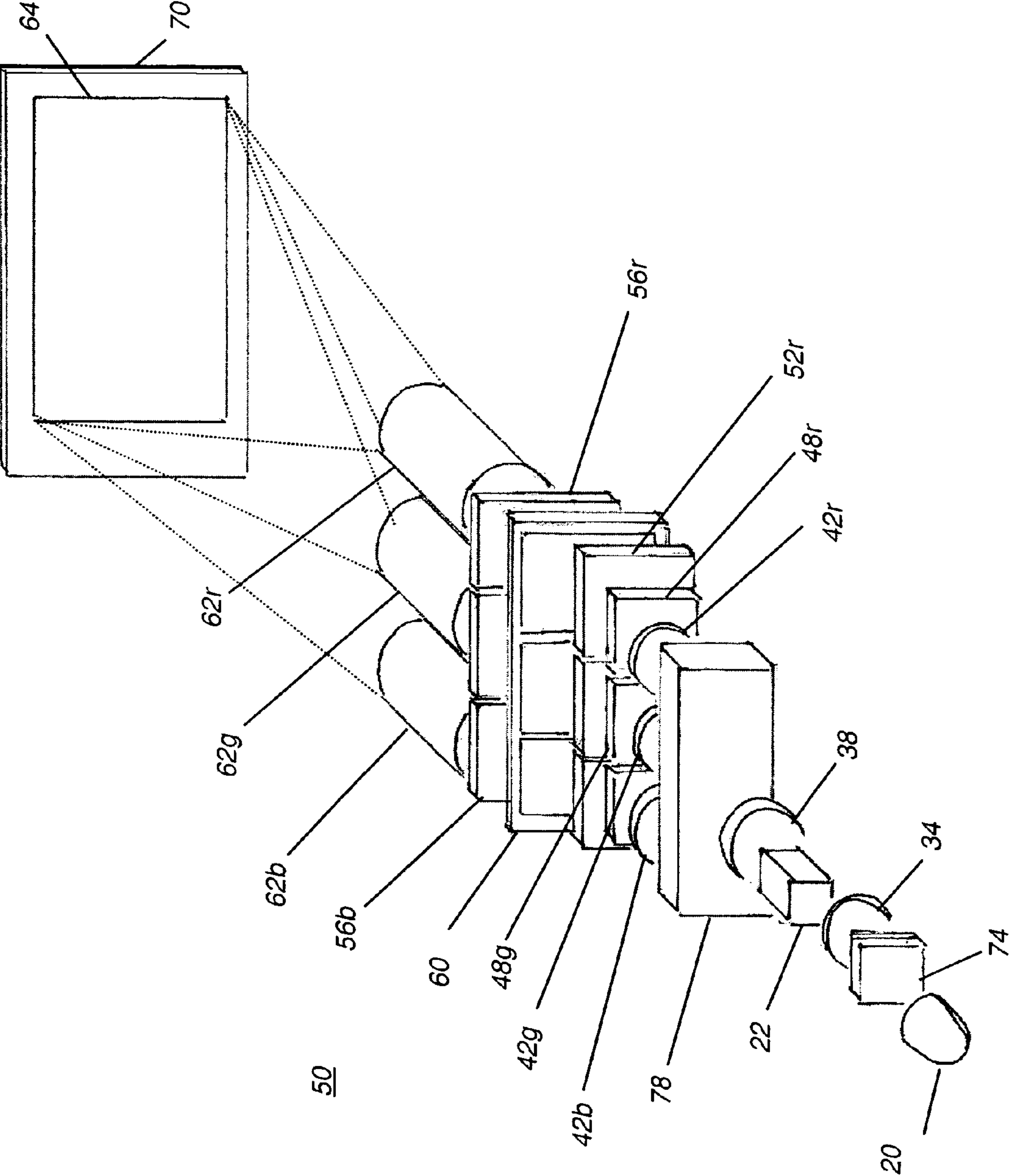


FIG. 4

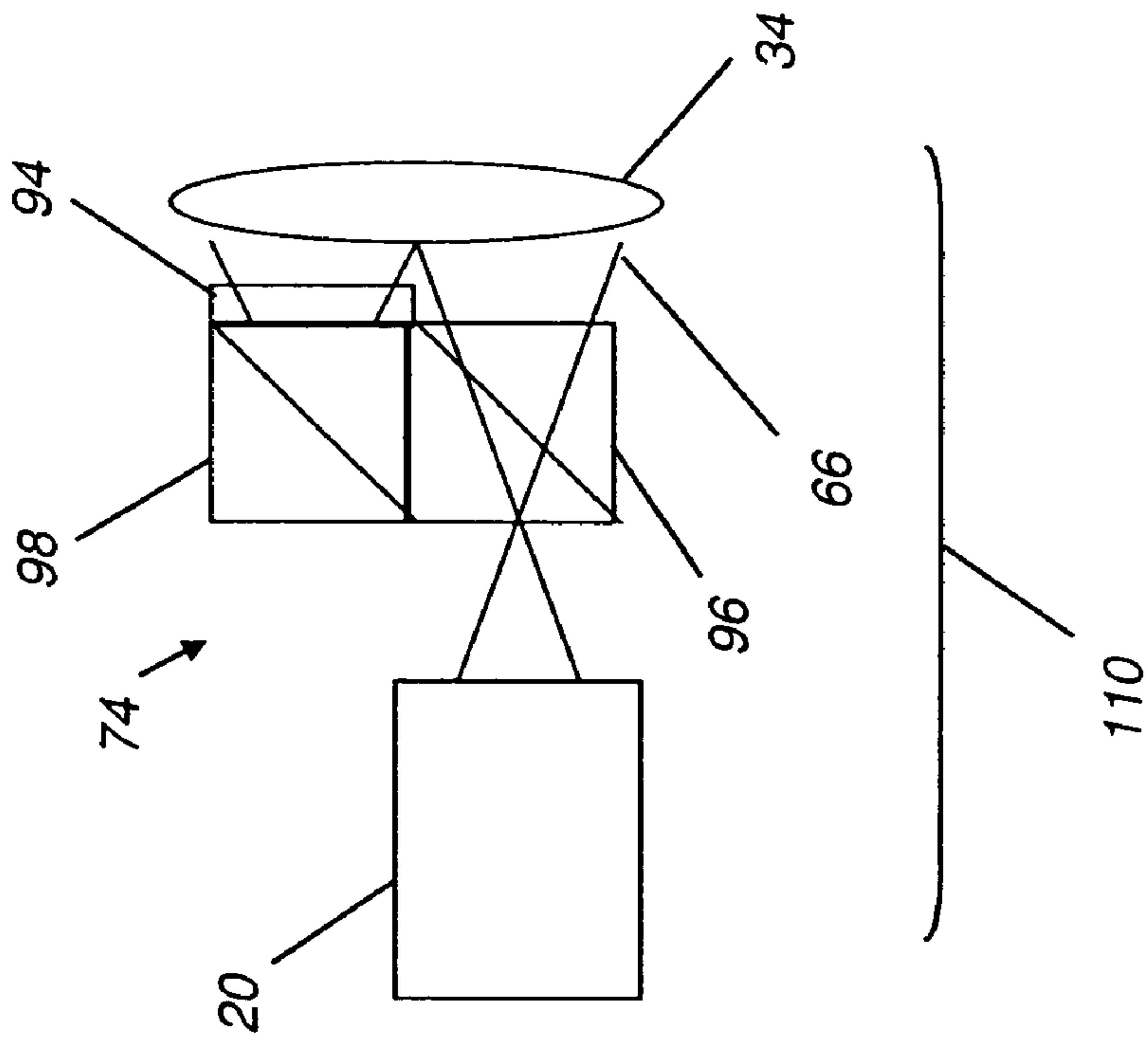


FIG. 5

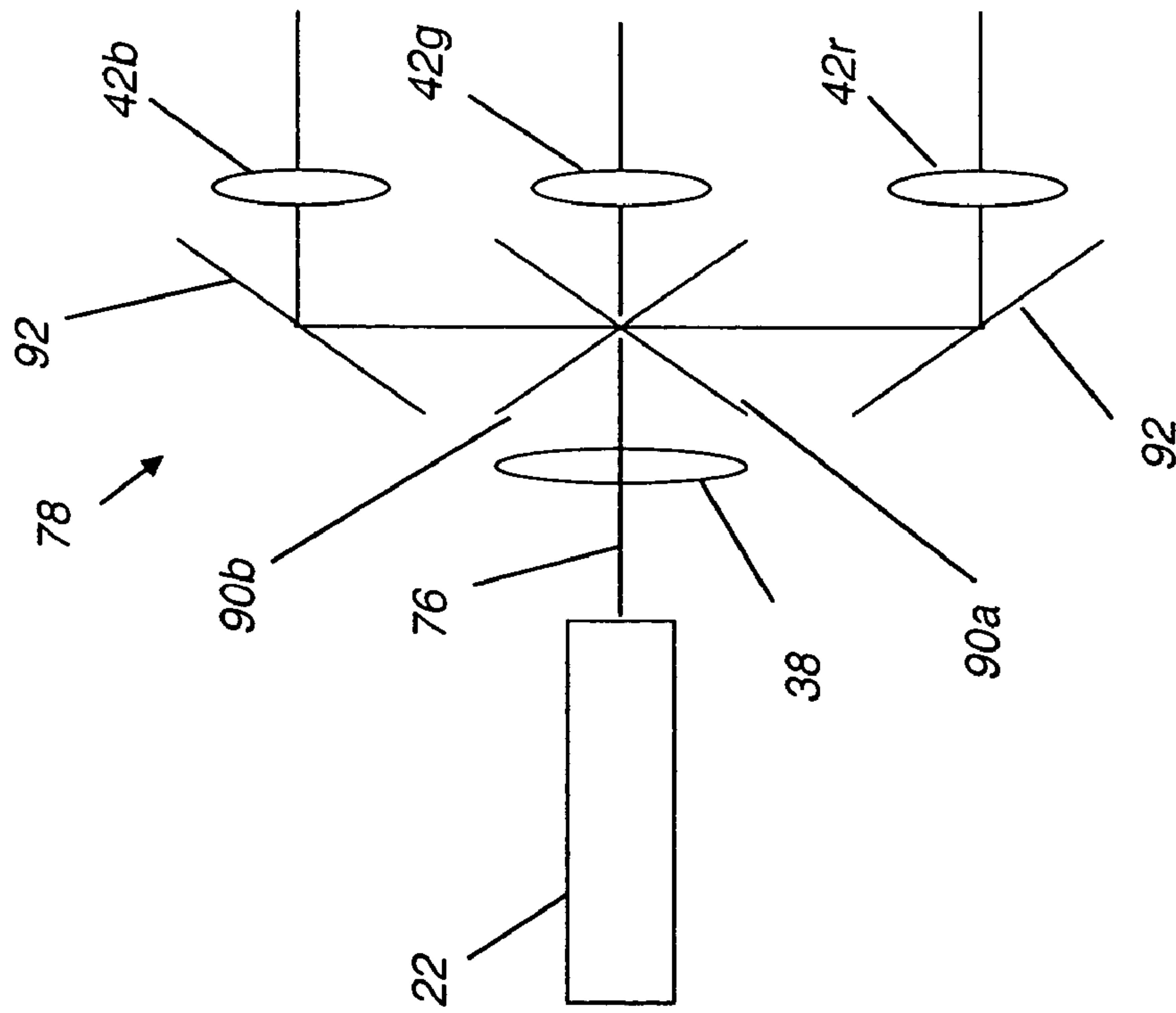


FIG. 6

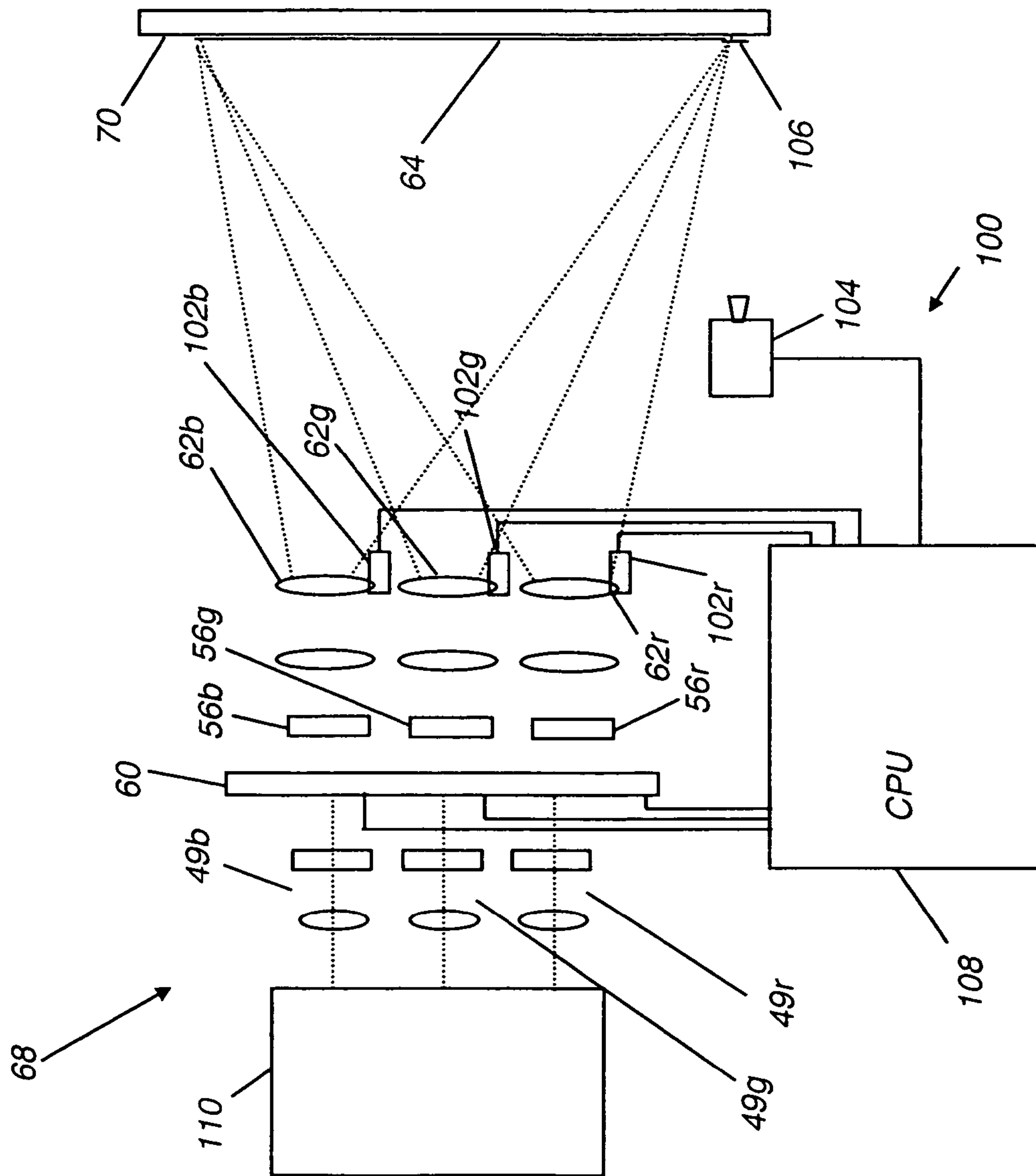


FIG. 7

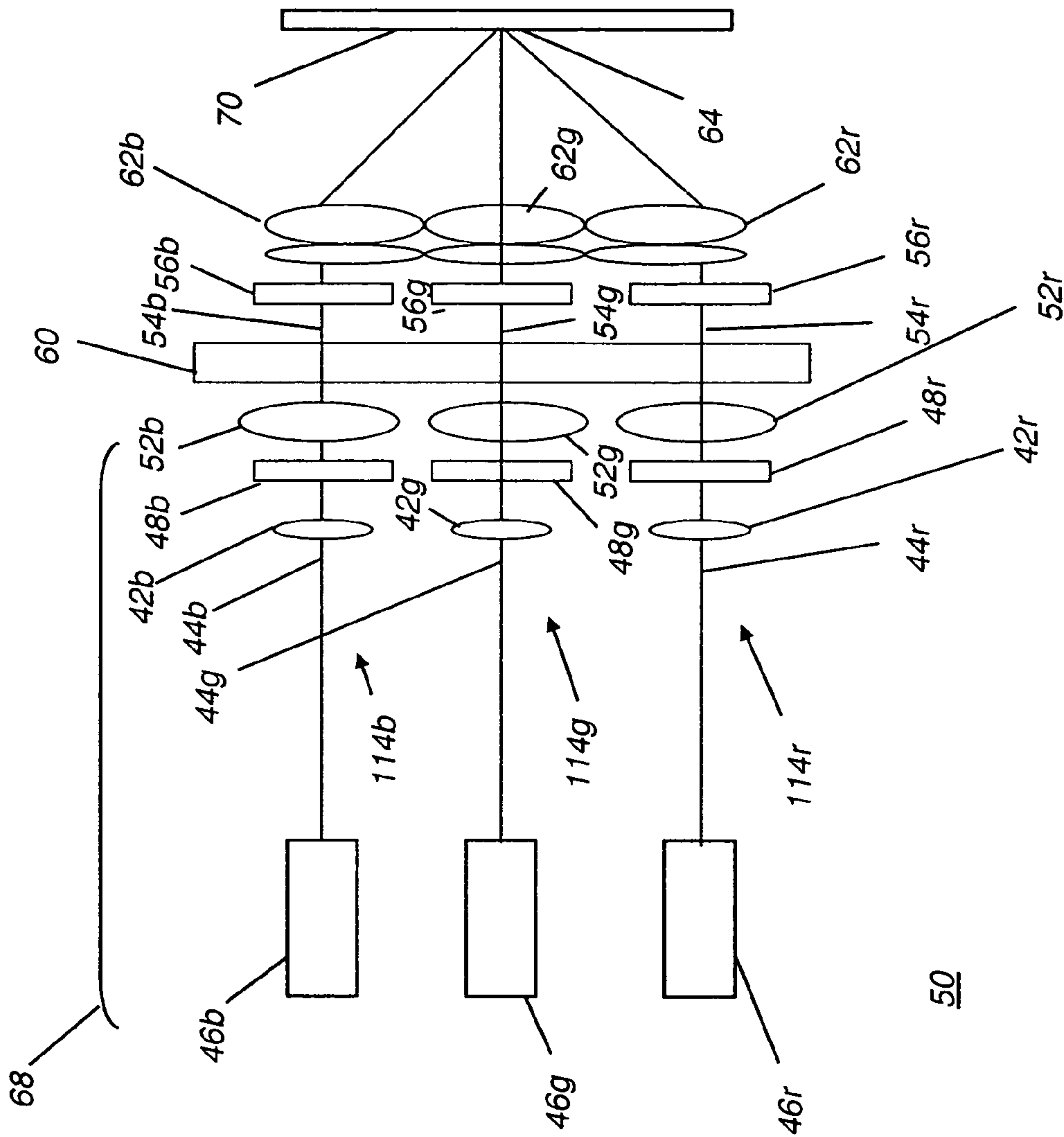


FIG. 8

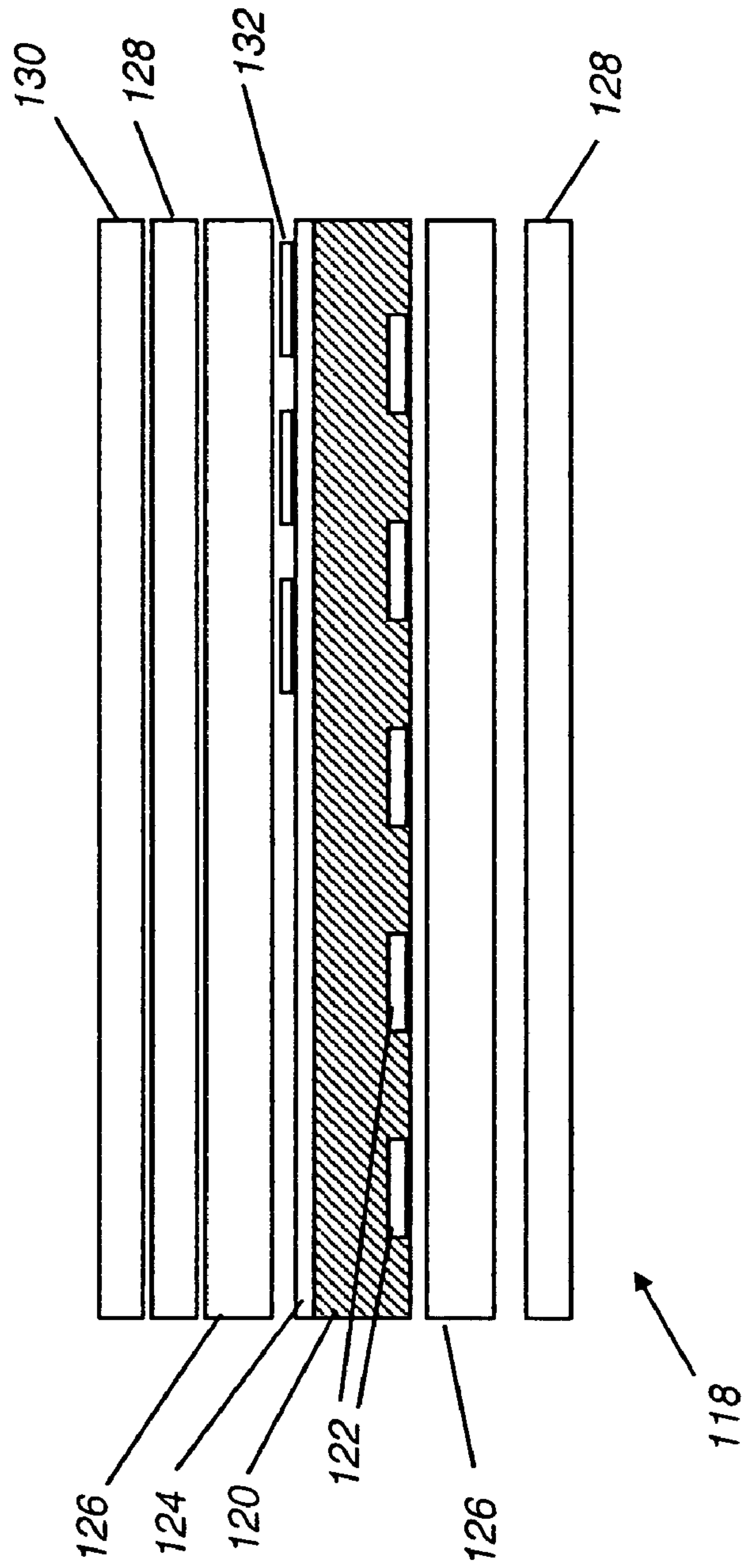


FIG. 9A

(PRIOR ART)

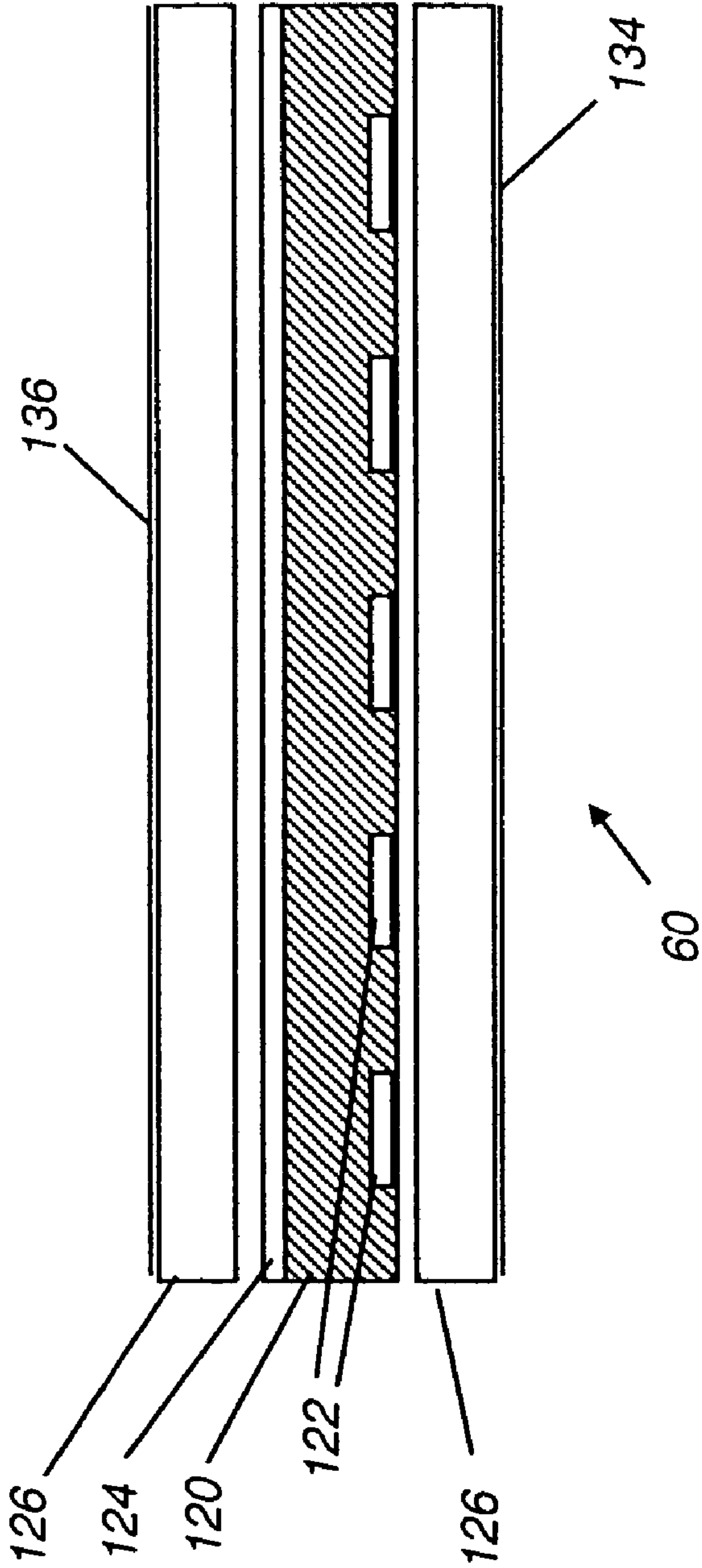


FIG. 9B

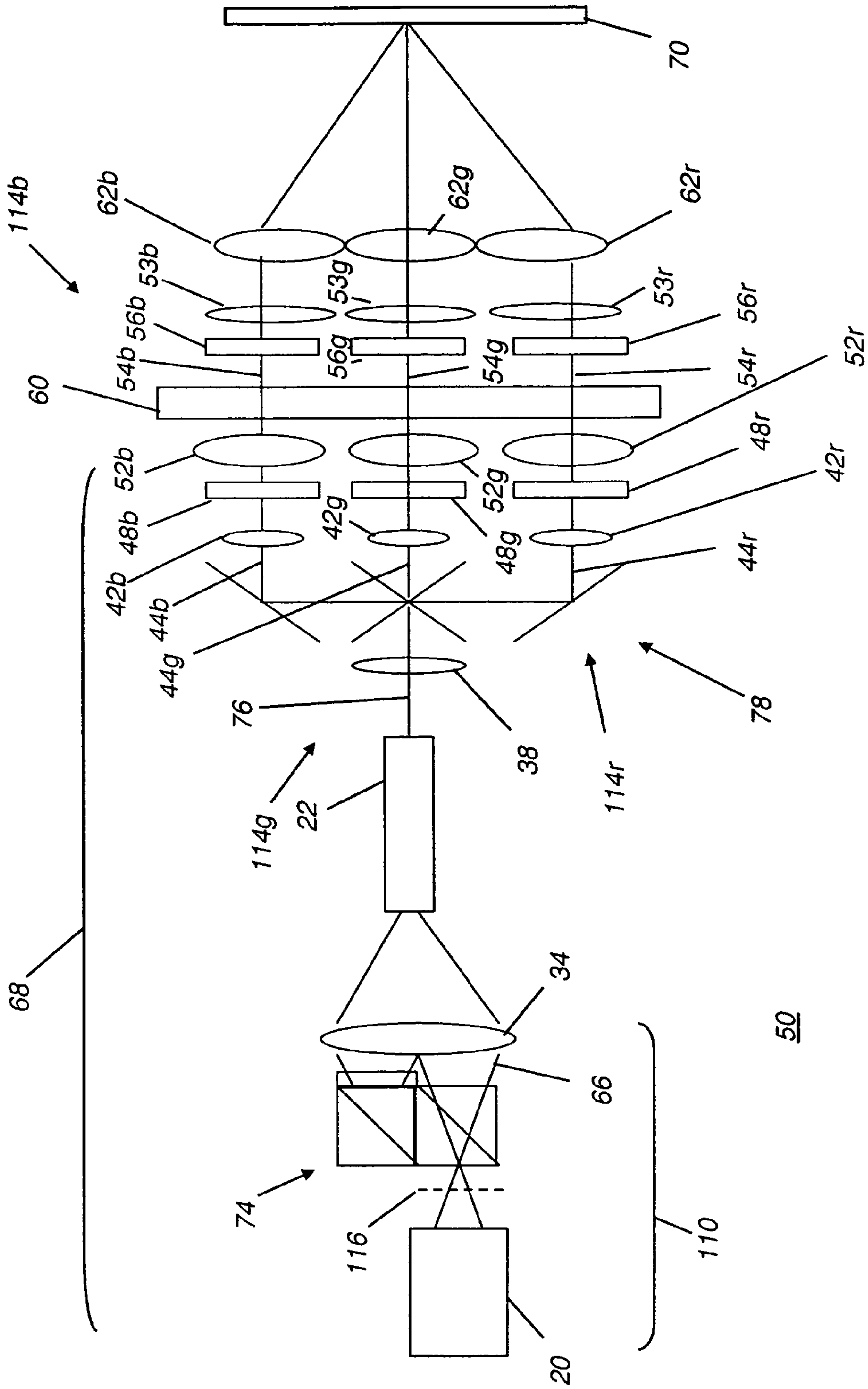


FIG. 10

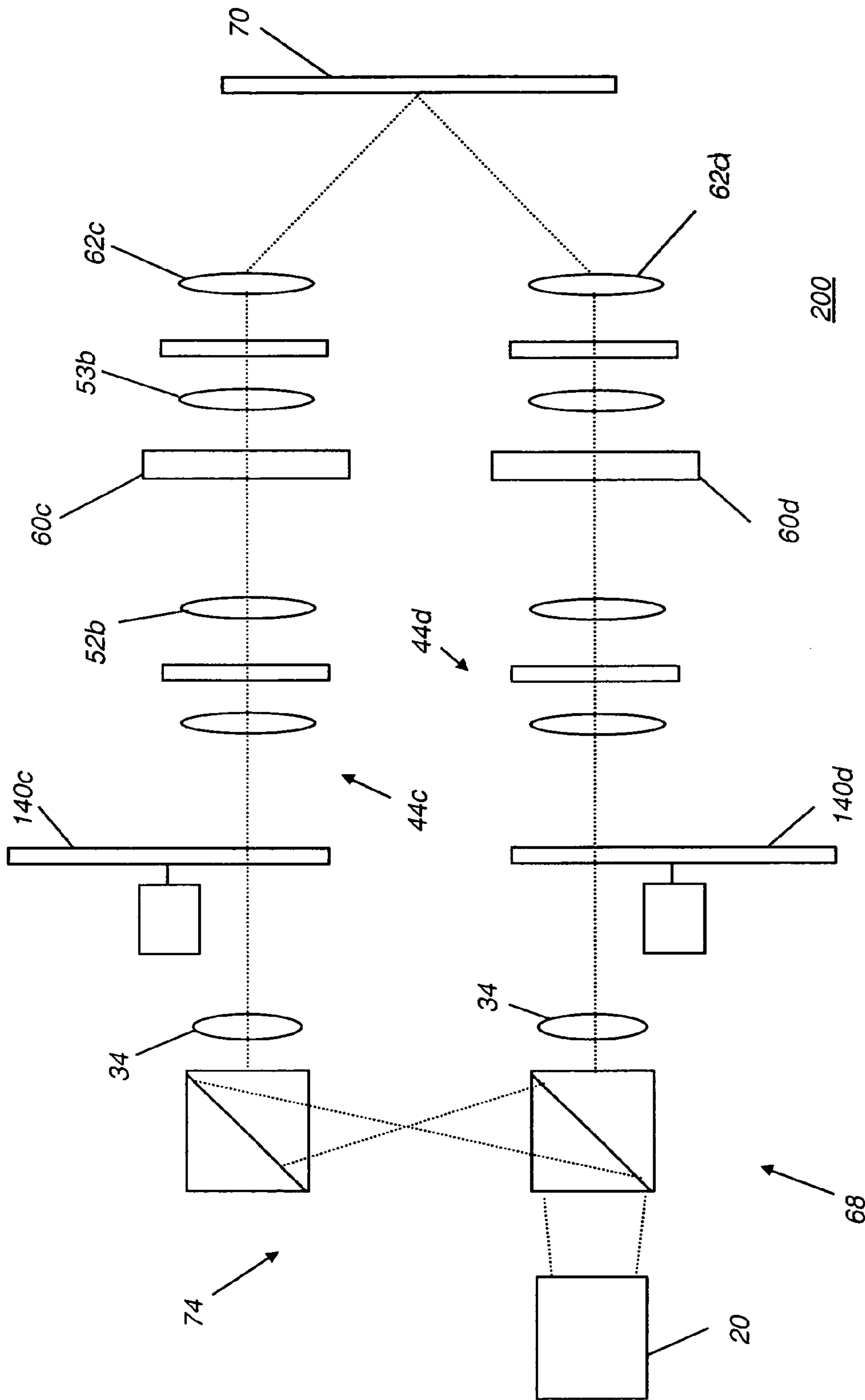


FIG. 11

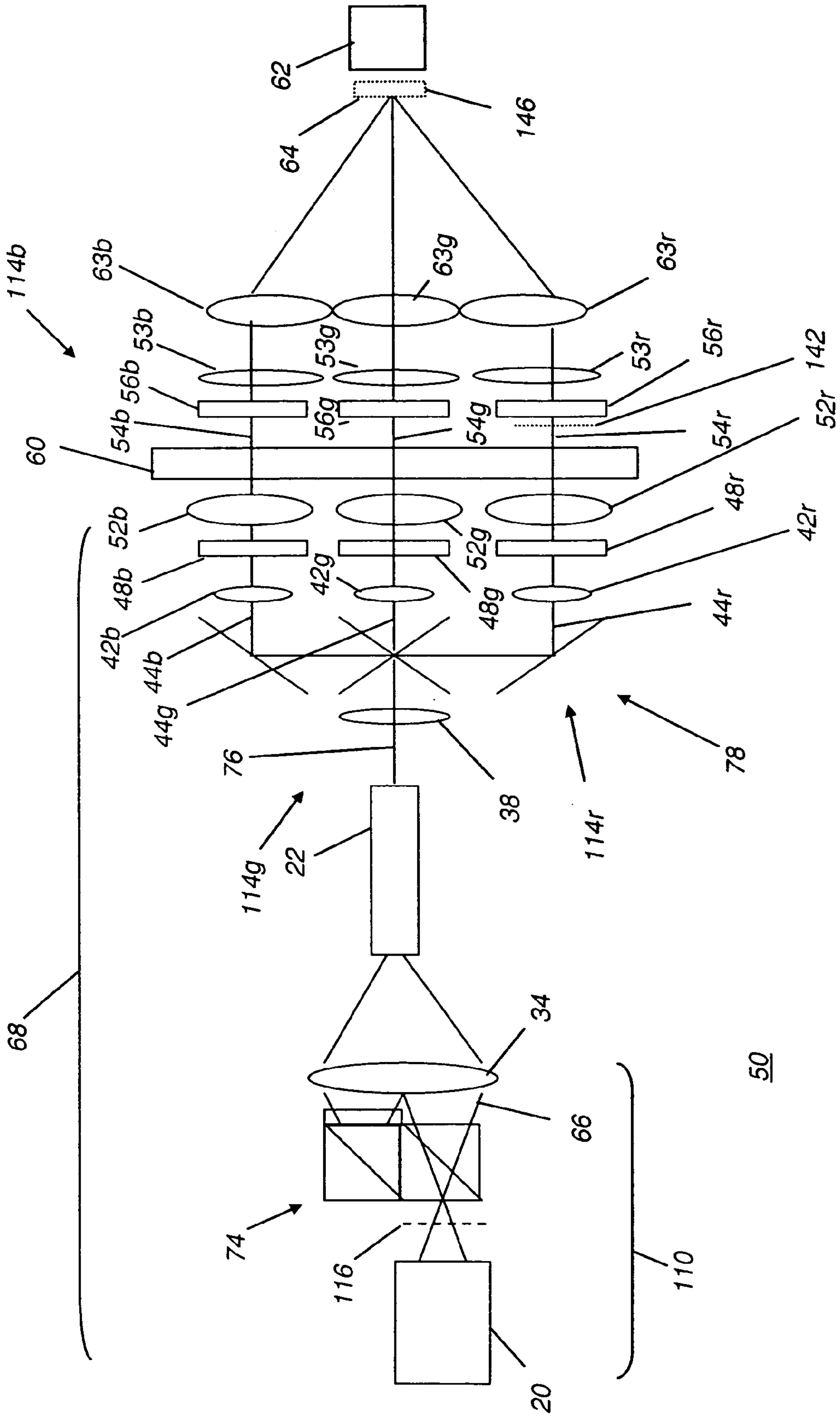


FIG. 12

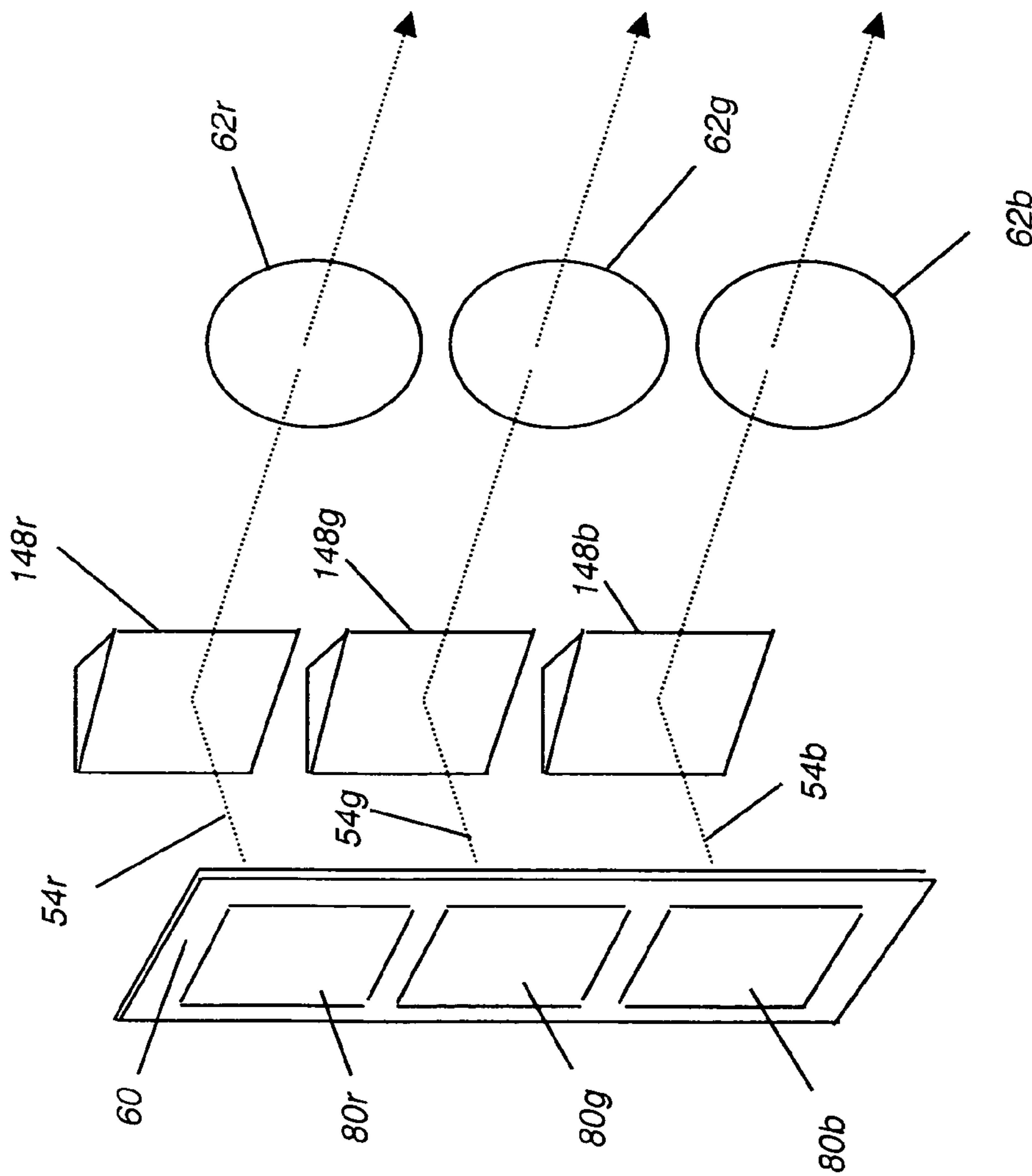


FIG. 13

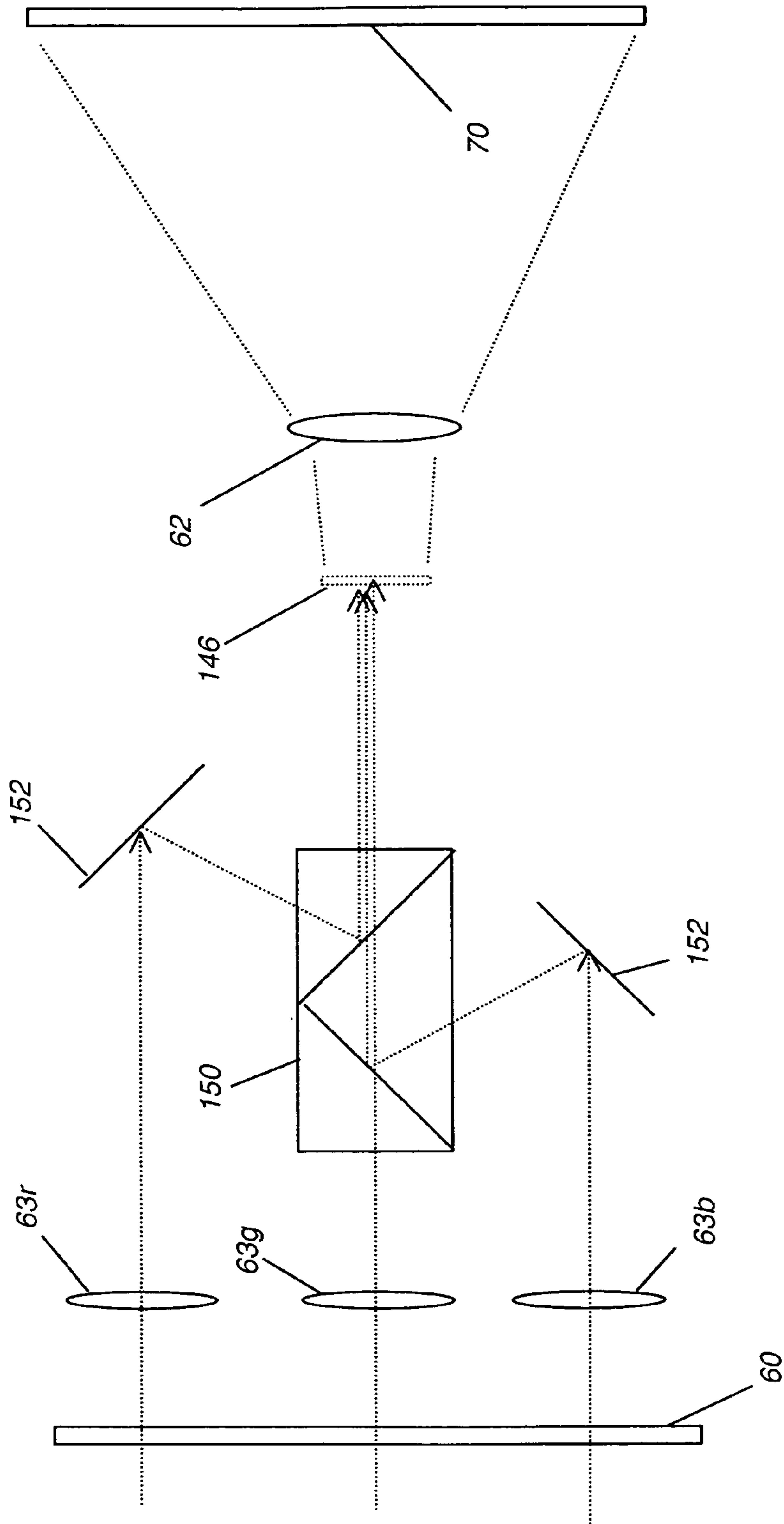


FIG. 14

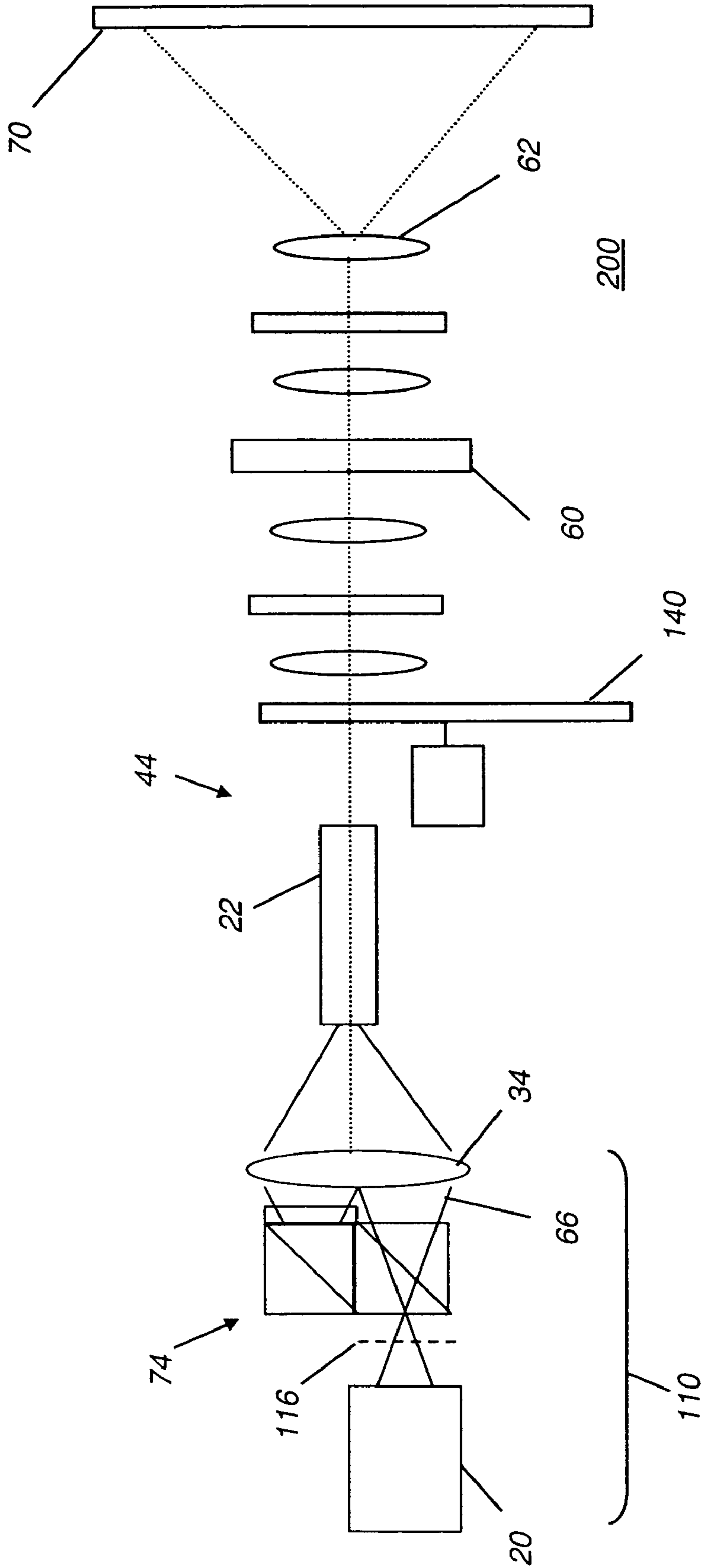


FIG. 15

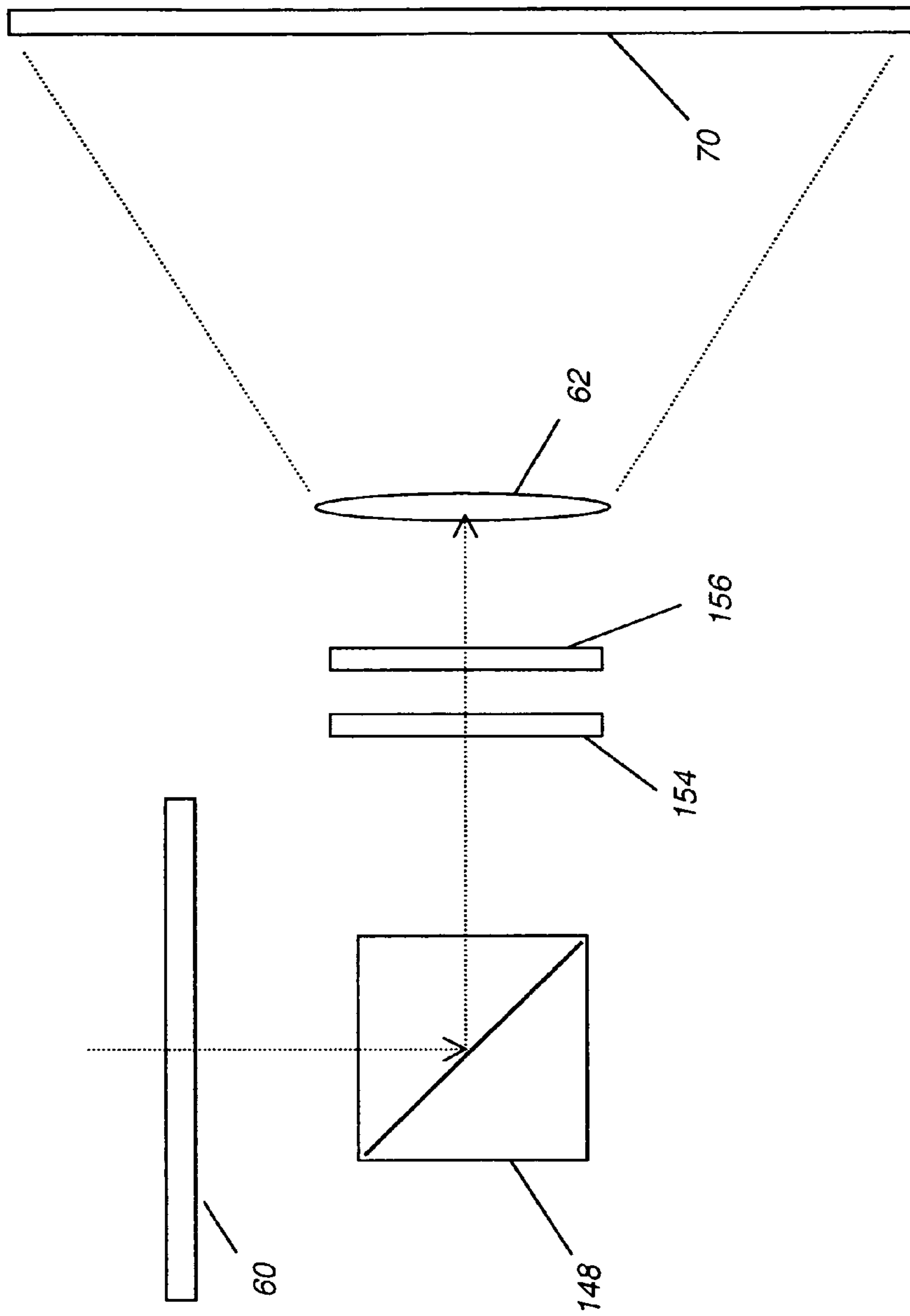


FIG. 16

DISPLAY APPARATUS USING LCD PANEL

FIELD OF THE INVENTION

This invention generally relates to electronic projection and more particularly relates to an electronic projection apparatus using a single LC modulator panel for forming a full color projection image.

BACKGROUND OF THE INVENTION

Liquid crystal (LC) technology has been successfully harnessed to serve numerous display applications, ranging from monochrome alphanumeric display panels, to laptop computers, and even to large-scale full color displays. As is well known, an LC device forms an image as an array of pixels by selectively modulating the polarization state of incident light for each corresponding pixel. Continuing improvements of LC technology have yielded the benefits of lower cost, improved yields and reliability, and reduced power consumption and with steadily improved imaging characteristics, such as resolution, speed, and color.

One type of LC display component, commonly used for laptops and larger display devices, is the so-called "direct view" LCD panel, in which a layer of liquid crystal is sandwiched between two sheets of glass or other transparent material. Continuing improvement in thin-film transistor (TFT) technology has proved beneficial for direct view LCD panels, allowing increasingly denser packing of transistors into an area of a single glass pane. In addition, new LC materials that enable thinner layers and faster response time have been developed. This, in turn, has helped to provide direct view LCD panels having improved resolution and increased speed. Thus, larger, faster LCD panels having improved resolution and color are being designed and utilized successfully for full motion imaging.

Alternatively, miniaturization and the utilization of microlithographic technologies have enabled development of LC devices of a different type. Liquid crystal on silicon (LCOS) technology has enabled the development of highly dense spatial light modulators by sealing the liquid crystal material against the structured backplane of a silicon circuit. Essentially, LCOS fabrication combines LC design techniques with complementary metal-oxide semiconductor (CMOS) manufacturing processes.

Using LCOS technology, LC chips having imaging areas typically smaller than one square inch are capable of forming images having several million pixels. The relatively mature level of silicon etching technology has proved to be advantageous for the rapid development of LCOS devices exhibiting high speeds and excellent resolution. LCOS devices have been used as spatial light modulators in applications such as rear-projection television and business projection apparatus.

With the advent of digital cinema and related electronic imaging opportunities, considerable attention has been directed to development of electronic projection apparatus. In order to provide a competitive alternative to conventional cinematic-quality film projectors, digital projection apparatus must meet high standards of performance, providing high resolution, wide color gamut, high brightness, and frame-sequential contrast ratios exceeding 1,000:1. LCOS LCDs appear to have advantages as spatial light modulators for high-quality digital cinema projection systems. These advantages include relatively large device size, small gaps between pixels, and favorable device yields.

Referring to FIG. 1, there is shown a simplified block diagram of a conventional electronic projection apparatus 10 using LCOS LCD devices. Each color path (r=red, g=green, b=blue) uses similar components for forming a modulated light beam. Individual components within each path are labeled with an appended r, g, or b, appropriately. Following the red color path, a red light source 20_r provides unmodulated light, which is conditioned by uniformizing optics 22_r to provide a uniform illumination. A polarizing beamsplitter 24_r directs light having the appropriate polarization state to a spatial light modulator 30_r which selectively modulates the polarization state of the incident red light over an array of pixel sites. The action of spatial light modulator 30_r forms the red component of a full color image. The modulated light from this image, transmitted along an optical axis O_r, through polarizing beamsplitter 24_r, is directed to a dichroic combiner 26, typically an X-cube or a Philips prism. Dichroic combiner 26 combines the red, green, and blue modulated images from separate optical axes O_r/O_g/O_b to form a combined, multicolor image for a projection lens 32 along a common optical axis O for projection onto a display surface 40, such as a projection screen. Optical paths for blue and green light modulation are similar. Green light from green light source 20_g, conditioned by uniformizing optics 22_g is directed through a polarizing beamsplitter 24_g to a spatial light modulator 30_g. The modulated light from this image, transmitted along an optical axis O_g, is directed to dichroic combiner 26. Similarly red light from red light source 20_r, conditioned by uniformizing optics 22_r is directed through a polarizing beamsplitter 24_r to a spatial light modulator 30_r. The modulated light from this image, transmitted along an optical axis O_r, is directed to dichroic combiner 26.

Among examples of electronic projection apparatus that utilize LCOS LCD spatial light modulators with an arrangement similar to that of FIG. 1 are those disclosed in U.S. Pat. No. 5,808,795 (Shimomura et al.); U.S. Pat. No. 5,798,819 (Hattori et al.); U.S. Pat. No. 5,918,961 (Ueda); U.S. Pat. No. 6,010,221 (Maki et al.); U.S. Pat. No. 6,062,694 (Oikawa et al.); U.S. Pat. No. 6,113,239 (Sampsel et al.); and U.S. Pat. No. 6,231,192 (Konno et al.)

As each of the above-cited patents shows, developers of motion-picture quality projection apparatus have primarily directed their attention and energies to LCOS LCD technology, rather than to solutions using TFT-based, direct view LC panels. There are a number of clearly obvious reasons for this. For example, the requirement for making projection apparatus as compact as possible argues for the deployment of miniaturized components, including miniaturized spatial light modulators, such as the LCOS LCDs or other types of compact devices such as digital micromirrors. The highly compact pixel arrangement, with pixels typically sized in the 10–20 micron range, allows a single LCOS LCD to provide sufficient resolution for a large projection screen, requiring an image in the range of 2048×1024 or 4096×2048 pixels or better as required by Society of Motion Picture and Television Engineers (SMPTE) specifications for digital cinema projection. Other reasons for interest in LCOS LCDs over their direct-view LCD panel counterparts relates to performance attributes of currently available LCOS components, attributes such as response speed, color, and contrast.

Yet another factor that tends to bias projector development efforts toward miniaturized devices relates to the dimensional characteristics of the film that is to be replaced. That is, the image-forming area of the LCOS LCD spatial light modulator, or its digital micromirror device (DMD) counterpart, is comparable in size to the area of the image frame that is projected from the motion picture print film.

This may somewhat simplify some of the projection optics design. However, this interest in LCOS LCD or DMD devices also results from an unquestioned assumption on the part of designers that image formation at smaller dimensions is most favorable. Thus, for conscious reasons, and in line with conventional reasoning and expectations, developers have assumed that the miniaturized LCOS LCD or DMD provides the most viable image-forming component for high-quality digital cinema projection.

One problem inherent with the use of miniaturized LCOS and DMD spatial light modulators relates to brightness and efficiency. As is well known to those skilled in the imaging arts, any optical system is constrained by the Lagrange invariant. A product of the area of the light-emitting device and the numerical aperture of the emitted light, the LaGrange invariant is an important consideration for matching the output of one optical system with the input of another and determines output brightness of an optical system. In simple terms, only so much light can be provided from an area of a certain size. As the LaGrange invariant shows, when the emissive area is small, a large angle of emitted light is needed in order to achieve a certain level of brightness. Added complexity and cost result from the requirement to handle illumination at larger angles. This problem is noted and addressed in commonly-assigned U.S. Pat. No. 6,758,565 (Cobb et al.); U.S. Pat. No. 6,808,269 (Cobb); and U.S. Pat. No. 6,676,260 (Cobb et al.) These patents disclose electronic projection apparatus design using higher numerical apertures at the spatial light modulator for obtaining the necessary light while reducing angular requirements elsewhere in the system.

A related consideration is that image-forming components also have limitations on energy density. With miniaturized spatial light modulators, and with LCOS LCDs in particular, only so much energy density can be tolerated at the component level. That is, a level of brightness beyond a certain threshold level can damage the device itself. Typically, energy density above about 15 W/cm² would be excessive for an LCOS LCD. This, in turn, constrains the available brightness when using an LCOS LCD of 1.3 inch in diameter to no more than about 15,000 lumens. Heat build-up must also be prevented, since this would cause distortion of the image, color aberrations, and could shorten the lifespan of the light modulator and its support components. In particular, the behavior of the absorptive polarization components used can be significantly compromised by heat build-up. This requires substantial cooling mechanisms for the spatial light modulator itself and careful engineering considerations for supporting optical components. Again, this adds cost and complexity to optical system design.

Still other related problems with LCOS LCDs relate to the high angles of modulated light needed. The mechanism for image formation in LCD devices and the inherent birefringence of the LCD itself limit the contrast and color quality available from these devices when incident illumination is highly angular. In order to provide suitable levels of contrast, one or more compensator devices must be used in an LCOS system. This, however, further increases the complexity and cost of the projection system. An example of this is disclosed in commonly-assigned U.S. Pat. No. 6,831,722 (Ishikawa et al.), which discloses the use of compensators for angular polarization effects of wire grid polarizers and LCD devices. For these reasons, it can be appreciated that LCOS LCD and DMD solutions face inherent limitations related to component size and light path geometry.

There have been various projection apparatus solutions proposed using the alternative direct view TFT LC panels.

However, in a number of cases, these apparatus have been proposed for specialized applications, and are not intended for use in high-end digital cinema applications. For example, U.S. Pat. No. 5,889,614 (Cobben et al.) discloses the use of a TFT LC panel device as an image source for an overhead projection apparatus. U.S. Pat. No. 6,637,888 (Haven) discloses a rear screen TV display using a single subdivided TFT LC panel with red, green, and blue color sources, using separate projection optics for each color path. Commonly-assigned U.S. Pat. No. 6,505,940 (Gotham et al.) discloses a low-cost digital projector with a large-panel LC device encased in a kiosk arrangement to reduce vertical space requirements. While each of these examples employs a larger LC panel for image modulation, none of these designs is intended for motion picture projection at high resolution, having good brightness levels, color comparable to that of conventional motion picture film, acceptable contrast, and a high level of overall image quality.

One attempt to provide a projection apparatus using TFT LC panels is disclosed in U.S. Pat. No. 5,758,940 (Ogino et al.) In the Ogino et al. '940 apparatus, one or more Fresnel lenses is used to provide collimated illumination to the LC panel; another Fresnel lens then acts as a condenser to provide light to projection optics. Because it provides an imaging beam over a wide area, the Ogino et al. '940 apparatus is advantaged for its high light output, based on the Lagrange invariant described above. However, while it offers potential applications for TV projection apparatus and small-scale projectors, the proposed solution of the Ogino et al. '940 disclosure falls short of the performance levels necessary for high-resolution projection systems that modulate light and provide imaged light output having high intensity, at levels of 10,000 lumens and beyond.

Thus, it can be seen that, although digital cinema projection apparatus solutions have focused on the use of LCOS LCDs for image forming, there are inherent limitations in brightness and efficiency when using LCOS LCD components for this purpose. TFT LC panel solutions, meanwhile, would provide enhanced brightness levels over LCOS solutions. While projection apparatus using TFT LC panels have been disclosed, these have not been well suited to the demanding brightness requirements of high-performance digital cinema projection.

In cinema applications, the projector projects the modulated image onto a display screen or surface, where this surface may be at a variable distance from the projector. This requires that the projector provide some type of focus adjustment as well as color alignment adjustment. With conventional LCOS apparatus such as that shown in FIG. 1, color alignment is performed by color combining optics, so that the three composite RGB colors are projected along the same axis. However, for solutions using TFT devices, there would be benefits to providing separate projection optics for red, green, and blue paths. Some of these benefits include simpler and less costly lenses with color correction for a narrow wavelength band at each lens. With such an approach, some alignment method must then be provided to form the color image from properly superimposed red, green, and blue images, thereby allowing the projector to be used over a range of distances from a display screen.

Other problems relate to the nature of light modulation by the TFT LC device and to the support components necessary for high brightness applications requiring high levels of image quality. Conventional solutions would constrain both the light output levels and overall image quality, obviating the advantages afforded by TFT use for projection applications. For example, the use of absorptive polarizers directly

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attached to the TFT panels, as these devices are commonly provided, is disadvantageous for image quality. Heat absorption from these films, typically exceeding 20% of the light energy, causes consequent heating of the LCD materials, resulting in a loss of contrast and contrast uniformity.

Thus, it can be seen that there is a need for a full-color projection apparatus that takes advantage of inherent etendue-related advantages of TFT LC devices and provides improved image quality.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a projection apparatus comprising:

- a) an illumination section comprising:
 - i) a first light source for providing a first illumination beam;
 - ii) a second light source for providing a second illumination beam;
 - iii) a third light source for providing a third illumination beam;
- b) first, second, and third component wavelength modulating sections, each component wavelength modulating section accepting the corresponding first, second, or third wavelength illumination and modulating the corresponding wavelength illumination to provide a first, second, or third modulated component wavelength beam respectively, each component wavelength modulating section comprising:
 - i) a portion of a monochrome transmissive liquid crystal modulator panel that has been segmented into at least a first portion, a second portion, and a third portion, and wherein each portion is spatially separated from each other portion;
 - ii) a component wavelength polarizer in the path of the component wavelength illumination for directing substantially polarized light to the corresponding portion of the monochrome transmissive liquid crystal modulator panel;
 - iii) an illumination path Fresnel lens for focusing incident illumination from the component wavelength polarizer through the corresponding portion of the monochrome transmissive liquid crystal modulator panel;
 - iv) an analyzer for conditioning the polarization of the modulated component wavelength beam;
 - v) a lens for forming an image for projection onto a display surface; and

whereby the image formed on the display surface comprises a plurality of superimposed component wavelength beams.

It is a feature of the present invention that, unlike current approaches that use miniaturized LCOS LCDs, the apparatus of the present invention employs a single LCD panel for imaging in a projection apparatus intended for high-end electronic imaging applications.

It is an advantage of the present invention that it allows added brightness for the projected image. Various types of light sources could be used.

These and other objects, features, and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described an illustrative embodiment of the invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter of the present invention, it is believed that the invention will be better understood from the following description when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a block diagram showing a conventional projection apparatus using LCOS LCD devices;

FIG. 2 is a block diagram showing a projection apparatus using a large-scale TFT LC display according to the present invention;

FIG. 3 is a plan view of a TFT LC device segmented according to the present invention;

FIG. 4 is a perspective view of a projection apparatus according to the present invention;

FIG. 5 is a block diagram showing a projection apparatus with a control loop for alignment;

FIG. 6 is a plan view of an LCD modulator panel subdivided into component color modulating sections according to the present invention;

FIG. 7 is a schematic block diagram of a control loop for automated alignment of projection lenses in one embodiment;

FIG. 8 is a schematic block diagram showing a projection apparatus in an alternate embodiment;

FIG. 9A is a cross section of a conventional large panel LC device;

FIG. 9B is a cross section of a simplified large panel LC device according to the present invention;

FIG. 10 is a schematic block diagram showing an alternate embodiment with two Fresnel lenses in each color channel;

FIG. 11 is a schematic block diagram showing an alternate embodiment using color scrolling in a two panel apparatus;

FIG. 12 is a schematic block diagram showing an alternate embodiment in which an intermediate image is formed for projection;

FIG. 13 is a schematic diagram, in perspective, showing an alternate embodiment using a polarization beamsplitter in each color channel;

FIG. 14 is a schematic block diagram showing an alternate embodiment of a portion of a color projection apparatus using a V-prism as color combiner for modulated light;

FIG. 15 is a schematic block diagram showing an embodiment using a color wheel as color scrolling device; and,

FIG. 16 is a schematic block diagram showing the use of a polarization beamsplitter as an analyzer in one color channel.

DETAILED DESCRIPTION OF THE INVENTION

The present description is directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

Referring to FIG. 2, there is shown an embodiment of a projection apparatus 50 designed for large-scale, high-brightness projection applications according to an embodiment of the present invention. Unlike conventional projection apparatus described in the background section given above, projection apparatus 50 utilizes techniques to boost overall efficiency and light output, suited to the demanding requirements of high luminance projection. FIG. 4 shows

key components of projection apparatus **50** in a perspective view. FIG. **4** is representative for a configuration in which LC modulator panel **60** is segmented into three portions in side-by-side or horizontal fashion; this is an alternative to the configuration of FIG. **2** in which modulator panel **60** is segmented vertically. The best configuration for any particular embodiment, whether segmented vertically or horizontally, as described subsequently, would depend on the overall width:height aspect ratio of LC modulator panel **60** and the intended image **64**.

An illumination section **68** has a light source **20** for providing unpolarized illumination having multiple wavelengths, typically, white light. Light source **20** directs this illumination to a multiple wavelength polarizer **74** for providing a substantially polarized illumination beam **66**. A lens **34** directs polarized illumination beam **66** to a uniformizing element **22** to provide a uniformized polarized beam **76** having multiple wavelengths. A condensing lens **38** then directs uniformized polarized beam **76** to a color separator **78** that separates the multiple wavelengths into component color wavelengths, conventionally red, green, and blue (RGB) along separate illumination paths **44r** (red), **44g** (green) and **44b** (blue).

There are at least three component wavelength modulating sections **114r**, **114g**, **114b**, as shown in FIG. **2**, each aligned along a corresponding illumination path **44r**, **44g**, **44b**. In each component wavelength modulating section **114r**, **114g**, **114b**, a condensing lens **42r**, **42g**, **42b** directs the corresponding component wavelength illumination through a polarizer **48r**, **48g**, **48b**. Fresnel lenses **52r**, **52g**, and **52b** then focus this illumination through a monochrome transmissive liquid crystal modulator panel **60** that is segmented to handle each component color for modulation, as is described subsequently. Liquid crystal modulator panel **60** forms red, green, and blue component wavelength beams **54r**, **54g**, and **54b**. Component wavelength beams **54r**, **54g**, and **54b** are the modulated light beams that are combined to form the color image. Analyzers **56r**, **56g**, and **56b** condition the polarization of red, green, and blue component wavelength beams **54r**, **54g**, and **54b** prior to projection by projection lenses **62r**, **62g**, and **62b** that project each of the modulated component wavelength beams **54r**, **54g**, and **54b** respectively to a display surface **70**. Here, the modulated component wavelength beams **54r**, **54g**, and **54b** are superimposed to form a color image **64** on display surface **70**.

Broadband Polarization

Referring to FIG. **5**, exemplary components of multiple wavelength polarizer **74** in a polarized light providing apparatus **110** within illumination section **68** are shown in more detail. In this embodiment, a polarizer **96** transmits light having p-polarization and reflects light having s-polarization. A mirror **98**, or reflective polarization sensitive coating, then directs the light having s-polarization through a half wave plate **94**. Half wave plate **94** converts this incident light to p-polarization. In this way, polarized illumination beam **66** at lens **34** has the same polarization state. Thus, substantially all of the light output from light source **20** is converted to light having the same polarization state for modulation. This method provides light over a wider area and can be used with larger transmissive LC panels. Conventional LCOS LCD projection systems, limited by the LaGrange invariant, cannot fully take advantage of this type of light output.

In one embodiment, polarizer **96** is a wire grid polarizer, such as the polarizer type disclosed in U.S. Pat. No. 6,452,724 (Hansen et al.) Wire grid polarizers of various types are

commercially available from Moxtek, Inc., Orem, Utah. The wire grid type of polarizer is particularly advantaged for handling high levels of light intensity, unlike conventional types of absorptive polarizer. In one embodiment this wire grid polarizer would be placed such that its wire elements on its wire surface side face toward the LCD panel. This configuration reduces thermally induced birefringence as disclosed in commonly assigned U.S. Pat. No. 6,585,378 (Kurtz et al.) Polarizer **96** could alternately be a conventional prism polarizer, such as a MacNeille polarizer, familiar to those skilled in the electronic imaging arts.

Illumination Source and Optics

A notable improvement over conventional TFT LC projection apparatus is the use of uniformizing optics **22** for providing a uniform illumination from a light source **20**. Uniformizing optics **22** condition the output from light source **20** to provide a uniformly bright illumination beam for modulation. In one embodiment, an integrating bar provides uniformizing optics **22**. Alternate embodiments include the use of a lenslet array or some combination of lenslet and other integrating components.

Light source **20** can be any of a number of types of lamp or other emissive component. It can be appreciated that it would be particularly advantageous to select a commercially available component as light source **20**, to take advantage of low cost and availability due to high manufacturing volumes. In one embodiment, a conventional CERMAX® xenon arc lamp, available from PerkinElmer Inc., Wellesley, Mass., is used. The capability to use such off-the-shelf devices is a particular advantage when using a larger size TFT LC device, as opposed to using smaller LCOS components that typically require custom light source solutions. Other alternative light sources include high-power LEDs, which can be distributed in an array when using uniformizing optics **22**. Another option is to use ultra-high pressure Mercury lamps, for example. Conventional xenon bubble lamps offer yet another option and provide better color gamut than Mercury lamps.

An optional shutter **116**, whose position may be at the location of the dotted line in FIG. **2**, may be implemented within illumination system **68** in order to momentarily darken the display to allow time for a suitable transition between images. Shutter **116** may be needed depending on LC modulator panel **60** response speed. Although response speeds of LC modulator panels **60** have improved sufficiently for conventional video, it remains to be seen if there will be sufficient improvement to allow imaging with ghost free motion, particularly with image content that contains considerable action and transitions. Shutter **116** would be used to block the light to LC modulator panel **60** during transition times, effectively reducing the overlay of images between frames. A suitable shutter mechanism is disclosed, for example, in commonly-assigned U.S. Pat. No. 6,513,932 (Ehrne et al.)

Color Separation

As was shown in FIG. **2**, uniformized polarized beam **76** that is output from uniformizing optics **22** next goes to color separator **78**. FIG. **6** shows the components of color separator **78** in more detail. An arrangement of crossed dichroic surfaces **90a**, **90b** is used to split the multiple wavelength light of uniformized polarized beam **76** into the key red, green, and blue component wavelengths for modulation as red, green, and blue component wavelength beams **54r**, **54g**, and **54b**, respectively. Turning mirrors **92** redirect red and blue component wavelength beams **54r** and **54b** in the embodiment of FIG. **6**. Alternate embodiments include use

of dichroic separating components in a fashion such that more than three color bands are separated, enabling a larger color gamut.

The improved light efficiency afforded by modulator panel **60** can be utilized to provide a projection gamut that is substantially larger than that provided using conventional video, such as SMPTE "C" color space or even proposed digital cinema SMPTE gamut defined by (Red: 0.680 x, 0.320 y, 10.1 Y, Green: 0.265 x, 0.690 y, 34.6 Y, Blue: 0.150 x, 0.060 y, 3.31 Y). There is interest in making the gamut at least as large or larger than that of motion picture film. Dichroic filters can be selected and positioned to block portions of the spectral bands between the typical component color bands blue, green, and red, thereby increasing the color space that projection apparatus **10** works within.

Configuration of Modulator Panel **60**

One aspect of the present invention relates to the segmentation of monochrome liquid crystal modulator panel **60**, as shown in the plan view of FIG. **6**. The red, green, and blue component colors in respective red, green, and blue illumination paths **44r**, **44g**, and **44b** (FIG. **2**) are modulated by a red component modulating section **80r**; a green component modulating section **80g**, and a blue component modulating section **80b**, respectively. In one embodiment, where LC modulator panel **60** has 2048×3240 pixel resolution, each component color modulating section **80r**, **80g**, and **80b** has 2048×1080 pixel resolution. Higher resolution panel alternatives would be advantaged for applications such as digital cinema.

Each modulating section **80r**, **80g**, **80b** has a corresponding border portion **82r**, **82g**, **82b**. Border portions **82r**, **82g**, **82b** include some number of pixels that are unused but available to be used as part of modulating section **80r**, **80g**, **80b**. Border portions **82r**, **82g**, **82b** are used to facilitate alignment of the component color modulated light, as is described subsequently.

Each modulating section **80r**, **80g**, **80b** is separated from its adjacent modulating section(s) **80r**, **80g**, **80b** by a light blocking segment **84a**, **84b**. Light blocking segments **84a**, **84b** consist of pixels in a dark or black state, acting as masks for reflecting overlapping light from adjacent red, green, and blue illumination paths **44r**, **44g**, and **44b**. Physical blocking elements may be used in addition to or in lieu of these dark state pixels.

In the embodiments of FIGS. **2–4**, LC modulator panel **60** is modified and simplified for use in a projection application. Referring first to FIG. **9A**, there is shown a conventional LC modulator panel **118** as provided by the manufacturer for display use. In this conventional arrangement, LC material **120**, with its control electrodes on an ITO layer **124** and thin-film transistors **122** is sandwiched between plates of glass **126**, along with a color filter array **132**. Front and rear polarizers **128** are absorptive sheets whose performance is compromised by high heat levels, causing variable thermal nonuniformities in the projected image. A compensation film **130** is also provided for enhancing contrast. In many devices, other enhancement films are used but not shown, such as diffusing layers.

FIG. **9B** shows the simplified arrangement of LC modulator panel **60** as used in the present invention. Compensation film **130** may be removed; even if maintained, the performance requirements and cost of compensation film **130** are significantly reduced. Front and rear polarizers **128** are also removed from LC modulator panel **60** itself; separate wire grid polarizers are used for polarizers **48r**, **48g**, **48b** and analyzers **56r**, **56g**, **56b**. Polarizers **48r**, **48g**, **48b** and

analyzers **56r**, **56g**, **56b** are spaced apart from the surface of glass sheets **126**. Wire grid polarizers, capable of handling high light levels without absorbing substantial amounts of light energy, are particularly well suited to high intensity application in projection apparatus **50**. Spacing them apart from LC material **120** prevents heat transfer that would negatively impact the uniformity of the image. Color filter array **132** is no longer needed. An optional antireflection coating **134**, **136** may be provided on both external surfaces of glass **126**. Antireflection coating **134**, **136** would help to reduce checkerboard effects and increase the ANSI contrast ratio, minimizing the interactions of neighboring pixels from stray light.

Fresnel Lenses

Use of Fresnel lenses **52r**, **52g**, and **52b** in illumination paths **44r**, **44g**, and **44b**, as shown in FIG. **2**, is particularly advantageous for directing light toward the entrance pupils of corresponding projection lenses **62r**, **62g**, and **62b**. By placing Fresnel lenses **52r**, **52g**, and **52b** in illumination paths **44r**, **44g**, and **44b**, imaging aberrations are minimized. Fresnel lenses are typically molded and may exhibit non-uniformities that are particularly visible if the lens is used with image-modulated light.

FIG. **10** shows an alternate embodiment using a pair of Fresnel lenses in each component wavelength modulating section **114r**, **114g**, and **114b**, one placed as an illumination path Fresnel lens in each illumination path **44r**, **44g**, **44b**, the other placed as a modulated beam Fresnel lens in each modulated component wavelength beam **54r**, **54g**, **54b**. In the blue color channel, Fresnel lens **52b** is in illumination path **44b**; a second Fresnel lens **53b** is in component wavelength beam **54b**. In the green color channel, Fresnel lens **52g** is in illumination path **44g**; a second Fresnel lens **53g** is in the modulated component wavelength beam **54g**. In the red color channel, Fresnel lens **52r** is in illumination path **44r**; a second Fresnel lens **53r** is in modulated component wavelength beam **54r**. With the arrangement of FIG. **10**, first Fresnel lens **52r**, **52g**, and **52b** in the illumination beam for each component wavelength modulating section **114r**, **114g**, **114b** reduces the angle of light directed into modulator panel **60**, providing a measure of collimation, thereby improving the contrast performance. The second Fresnel lens **53r**, **53g**, and **53b** would be placed in modulated component wavelength beam **54r**, **54g**, **54b** from LC modulator panel **60**, to direct the light toward the entrance pupils of corresponding projection lenses **62r**, **62g**, and **62b**.

In an alternate embodiment, a pair of crossed cylindrical Fresnel lenses can be used in one or more of component wavelength modulating sections **114r**, **114g**, **114b** as an alternative to the conventional circularly symmetric Fresnel lens types. Crossed cylindrical Fresnel lenses are rotated with respect to each other and can be further rotated at an angle to LC modulator panel **60** to minimize or eliminate moire and aliasing.

In one embodiment, projection apparatus **50** uses anti-ghost Fresnels, such as those produced by manufacturers such as Reflexite Corporation, Rochester, N.Y. As another alternative, holographic optical components could be used in the place of one or more of Fresnel lenses **52r**, **52g**, and **52b**. Glass molded Fresnel lenses would help to minimize problems with stress birefringence from light absorption, such as decreased contrast uniformity across the image.

Control Loop for Projection Lens **62r**, **62g**, **62b** Alignment

FIG. **7** shows a control loop **100** arranged for automated alignment of projection lenses **62r**, **62g**, and **62b**. A sensor **104**, such as an electronic camera, senses light from a target

106 that may be part of image **64** on display surface **70** or may be separated from image **64**. Target **106** is devised to show proper overlap of the modulated component color images projected onto display surface **70**. Methods such as those disclosed in commonly assigned U.S. Pat. No. 6,793, 351 (Nelson et al.) may be used to detect proper overlap at a control logic processor **108** and to counter any offset between colors detected by sensor **104**. Adjustment of projection lenses **62r**, **62g**, and **62b** may be effected using a combination of methods. Alignment in units of complete pixels can be accomplished electronically, by shifting the position of the corresponding red, green, or blue component modulating sections **80r**, **80g**, and **80b**, using a method similar to that disclosed in U.S. Pat. No. 5,729,245 (Gove et al.) Corresponding actuators **102r**, **102g**, and **102b**, such as stepping motors or piezoelectric actuators can be used to effect fine tuning alignment adjustment, either of full pixels or of fractional increments of a pixel, by moving projection lenses **62r**, **62g**, and **62b** themselves. In one embodiment, a combination of the two methods is used, first attempting alignment by shifting the relative positions of one or more of red, green, or blue component modulating sections **80r**, **80g**, and **80b**, utilizing pixels in border portions **82r**, **82g**, and **82b** as needed. Following this shifting of red, green, or blue component modulating sections **80r**, **80g**, and **80b**, fine tuning adjustment is then performed by driving actuators **102r**, **102g**, and **102b** as needed.

Alternate Embodiments

The embodiments shown in FIGS. 2, 4, 7, and 10 show projection apparatus **50** using the conventional set of red, green, and blue component colors. Other arrangements are possible, including the use of additional colors, to provide an enhanced color gamut. Or, different component colors could be used to form color image **64**. In an alternate embodiment using four colors, two LC modulator panels **60** could be used, each LC modulator panel **60** configured to have two component-color modulating sections.

In an alternate embodiment, a single LC modulator panel **60** is used in combination with a scrolling color filter device that separates the light into color bands, separated by light blocking regions. The color bands can be scanned across LC modulator panel **60** using prism optics or using a color wheel or other type of color scrolling mechanism. A blocking region is utilized to prevent color blurring during transition times between the colors. The modulator is subsequently modulated in synchronization with the particular color light provided to apply the appropriate portion of the composite color image. Scrolling color background and techniques are described, for example, in an article entitled "Sequential Color Recapture and Dynamic Filtering: A Method of Scrolling Color" by D. Scott Dewald, Steven M. Penn, and Michael Davis in SID 01 Digest, pages 1-4.

In the alternate embodiment shown in FIG. 15, a projection apparatus **200** uses a color scrolling element **140**, such as a color scrolling wheel or some combination of components including a color separator with a scanning prism, for example, that sequentially scans color light of various wavelengths using techniques familiar to those skilled in the digital projector arts. LC modulator panel **60** sequentially modulates each incident color of light provided from color scrolling element **140** to provide modulated light to a projection lens **62**.

Another alternate embodiment of projection apparatus **200**, as shown in FIG. 11, utilizes two modulator panels **60c** and **60d**, each with a color scrolling element **140c** and **140d**, respectively. Each modulator panel **60c**, **60d** has supporting

optical components in its corresponding illumination path **44c**, **44d**, similar to that described with reference to FIG. 2, and provides modulated light as a component wavelength beam **54c**, **54d** to a projection lens **62c**, **62d**. Illumination section **68** of these embodiments using color scrolling components could employ color separation, color scrolling and light-directing techniques similar to those disclosed in U.S. Pat. No. 6,280,034 (Brennesholtz), for example.

Where color scrolling element **140c**, or **140d** is a color scrolling wheel, a sequence utilizing repeated complementary pairs of colors may be particularly advantageous. In such an arrangement, color scrolling element **140c** could be a filter wheel having a red, green, and blue filter for forming its set of colors. Color scrolling element **140d** would then be a filter wheel having complementary cyan, magenta, and yellow filter for forming its set of colors. The sequencing of these filter wheels would be timed so that the combined image formed from the two modulator panels **60c**, **60d** would be additive with respect to color, with the combined image appearing to be white during each part of the scrolling sequence. This would be the case, for example, when simultaneously projecting each primary color (red, green, blue) paired with its corresponding complement color (cyan, magenta, yellow). Combining this approach with the advantages of enhanced brightness and improved imaging performance provided by the present invention allows an expanded color gamut over earlier designs.

In an alternate embodiment, instead of providing two separate modulator panels **60c**, **60d**, a single modulator panel **60** could be subdivided into two segments. This would provide an arrangement similar to that shown in FIG. 3, but with two segments instead of three as shown in the figure. One segment would serve for modulator panel **60c**, the other segment for modulator panel **60d**.

Another alternate embodiment entails combining images from the three color component wavelength modulating sections **114r**, **114g**, and **114b** at an intermediate image plane. Referring to FIG. 12, there is shown projection apparatus **50** wherein each component wavelength modulating section **114r**, **114g**, and **114b** provides a component of the modulated image to form image **64** as an intermediate image **146** for projection by a projection lens **62**. Lenses **63r**, **63g**, and **63b** direct modulated light to form intermediate image **146**. With this arrangement, intermediate image **146** may actually be smaller than modulator panel **60**, so that intermediate image **146** can be magnified to the large screen size by a single projection lens. Optical convergence can be done at the time of fabrication, so that only a single projection lens adjustment is necessary for an operator. This approach has been shown to be of value as demonstrated in commonly assigned U.S. Pat. No. 6,808,269 (Cobb) and U.S. Pat. No. 6,676,260 (Cobb et al.).

Referring to FIG. 8, there is shown a block diagram of projection apparatus **50** in an alternate embodiment using individual red, green, and blue light sources **46r**, **46g**, and **46b**. Light sources **46r**, **46g**, and **46b** may include lasers, LEDs, or other light source types and may also be supported by light conditioning components such as uniformizers, as were described with reference to FIG. 2. Light sources **46r**, **46g**, and **46b** may be polarized or provided with polarizers.

One advantage of the present invention is that compensators may not be needed or at least that the need for compensators may be minimized. As is well known in the art, there are two basic types of compensator films. An uniaxial film with its optic axis parallel to the plane of the film is called an A-plate. An uniaxial film with its optic axis perpendicular to the plane of the film is called a C-plate.

Alternately, the A-plate can be described as providing XY birefringence (an anisotropic medium with XY retardance) in the plane of the compensator, while the C-plate provides Z birefringence along the optical axis in the direction of beam propagation through the compensator. A uniaxial material with n_e greater than n_o is called positively birefringent. Likewise, a uniaxial material with n_e smaller than n_o is called negatively birefringent. Both A-plates and C-plates can be positive or negative depending on their n_e and n_o values. As is well known in art, C-plates can be fabricated by the use of uniaxially compressed polymers or casting cellulose acetate, while A-plates can be made by stretched polymer films such as polyvinyl alcohol or polycarbonate.

The present invention minimizes or eliminates the need for C-plate compensators, since using the larger LC panels as modulator panel **60** results in reduced angular sensitivity. Referring to FIG. **12**, a dotted line **142** indicates a possible position for an optional A-plate compensator in red component wavelength beam **54r**. Other component wavelength modulating sections **114r**, **114g**, and **114b** may also benefit from an A-plate compensator in a similar position. Alternately, a compensator could be disposed in the illumination path, such as prior to Fresnel lens **52r**, **52g**, **52b**, for example. In other embodiments, A-plate compensation may be supplemented with some additional level of C-plate compensation. In still other embodiments, a C-plate compensator would be sufficient. Any of a number of types of compensator can be used, including film based compensators, compensators formed from a multilayer thin film dielectric stack, and compensators using formed birefringent structures, for example.

In an alternate embodiment, as shown in the block diagram of a portion of a projection apparatus in FIG. **13**, shown in perspective for clarity, a polarization beamsplitter **148r**, **148g**, **148b** is provided as an analyzer for each modulated component wavelength beam **54r**, **54g**, **54b** from modulator panel **60**. Polarization beamsplitters **148r**, **148g**, **148b**, wire grid polarization beamsplitters in one embodiment, turn the optical path of each component wavelength beam **54r**, **54g**, **54b**. In the embodiment of FIG. **13**, projection lenses **62r**, **62g**, and **62b** then form an image on display surface **70**. In another alternate embodiment, an intermediate image could be formed, as was described above with reference to FIG. **12**.

Referring to FIG. **16**, there is shown a portion of a one color channel using a reflective polarization beamsplitter **148** as an analyzer. In this embodiment, an optional additional analyzer **154** can be used, along with a Fresnel lens **156**.

Referring to FIG. **14**, there is shown a schematic block diagram of an alternate embodiment in which modulated light from each color channel is directed by lens **63r**, **63g**, **63b** to a V-prism assembly **150**. V-prism assembly **150** combines the modulated light onto a single optical path for forming intermediate image **146** at the pupil of projection lens **62**. V-prism assembly **150** is one type of color combiner using dichroic surfaces and working in combination with mirrors **152** to direct light toward projection lens **62**. A commonly-assigned U.S. Pat. No. 6,676,260 (Cobb et al.) describes V-prism use in projection apparatus.

Where polarization beamsplitters **148r**, **148g**, **148b** are wire grid polarization beamsplitters, such as those provided by Moxtek, Inc., rotation of one of these devices about the optical axis can be used to provide a measure of compensation, using methods disclosed in commonly-assigned U.S. Pat. No. 6,805,445 (Silverstein et al.)

By comparison with the conventional projection apparatus **10** in FIG. **1**, the arrangement of projection apparatus **50** in FIGS. **2**, **4**, **8** and **12**, and projection apparatus **200** in FIG. **11** when adapted as described above, provides a system capable of considerably higher brightness levels. Where spatial light modulators **30r**, **30g**, and **30b** of the conventional arrangement in FIG. **1** are miniaturized LCOS LC devices, the LaGrange invariant and energy-carrying capacity of these devices constrains the amount of brightness that is available to a range from about 5,000 to no more than about 25,000 lumens. In contrast, the embodiment of FIGS. **2** and **4** enjoys an expanded luminance range, allowing projection in excess of 30,000 lumens.

The dimensions of LC modulator panel **60** can be optimized to suit the performance requirements of projection apparatus **50**. In contrast to the miniaturized LCOS LCD solutions previously used, LC modulator panel **60** can be a large scale device larger than typical laptop displays, up to 17–20 diagonal inches or more. Although early LC panels were disappointingly slow, ongoing work has provided speed improvements of 100% and better and it appears that increased speeds are feasible. Improved response times of 8 msec or shorter have been reported. Ideally, modulator panel **60** can be sized just big enough such that the full lamp system efficiency can be utilized and small enough to give the fastest response time, with the optimum size for pixel structure and electronics to be fabricated utilizing standard TFT panel methods.

Sizing a TFT panel to be best suited to the lamp system efficiency involves a number of considerations. For example, to utilize a Cermax style lamp with a 2.0 mm arc gap, measurements show that the full efficiency of the lamp can be captured by a system having a LaGrange invariant, defined as the product of the numerical aperture times the diagonal of the modulator area, of approximately 10. A system designed at f/10.0 has numerical aperture (NA) equal to 0.05. Thus, the device diagonal would need to be 200 mm. This value would need to be doubled in order to capture both polarization states. Additionally this modulation area would be required for each wavelength band chosen. Thus, from a system efficiency standpoint, a panel that is slightly larger than 1074×358 mm would be very efficient and offer the best potential for fast transition times. The main difficulty would be to fabricate pixel electronics to be small enough to accommodate this size at the high resolutions desired: 2048×1024 or 4096×2048 for each wavelength band modulated.

With its capability for using brighter light sources and use of a large-area image generator, projection apparatus **50** using TFT LC modulator panel **60** as in FIGS. **2** and **5** offers an overall efficiency on the order of 40–50%. This is in contrast to the typical efficiency of earlier LCOS LCD designs of FIG. **1**, where efficiencies of no more than about 5 to 10% are common. Wire grid polarizers are particularly advantageous, since they exhibit relatively low light absorption. In general, a polarizer having light absorption of less than about 20% would be preferred. There may also be improved performance obtained by orienting the wire grid surface itself toward modulator panel **60** in the embodiments described above.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention as described above, and as noted in the appended claims, by a person of ordinary skill in the art without departing from the scope of the invention. For example, the embodiments described

hereinabove can be used to form an intermediate image, as was described with reference to FIG. 12, or to provide color modulated beams that are separately projected onto display surface 70. Alternative types of more recently introduced TFT components are possible, including organic thin-film transistors (OTFTs) based on conjugated polymers, oligomers, or other molecules and thin film transistors utilizing monolayers of well-dispersed single wall carbon nanotubes.

Thus, what is provided is an apparatus and method for an electronic projection apparatus using a TFT LC panel for forming the projection image.

PARTS LIST

10 projection apparatus
 20 light source
 20*r* light source, red
 20*g* light source, green
 20*b* light source, blue
 22 uniformizing optics
 22*r* uniformizing optics, red
 22*g* uniformizing optics, green
 22*b* uniformizing optics, blue
 24*r* polarizing beamsplitter, red
 24*g* polarizing beamsplitter, green
 24*b* polarizing beamsplitter, blue
 26 dichroic combiner
 30*r* spatial light modulator, red
 30*g* spatial light modulator, green
 30*b* spatial light modulator, blue
 32 projection lens
 34 lens
 38 lens
 40 display surface
 42*r* condensing lens, red
 42*g* condensing lens, green
 42*b* condensing lens, blue
 44 illumination path
 44*c* illumination path
 44*d* illumination path
 44*r* illumination path, red
 44*g* illumination path, green
 44*b* illumination path, blue
 46*r* light source, red
 46*g* light source, green
 46*b* light source, blue
 48*r* polarizer, red
 48*g* polarizer, green
 48*b* polarizer, blue
 50 projection apparatus
 52*r* Fresnel lens, red
 52*g* Fresnel lens, green
 52*b* Fresnel lens, blue
 53*r* Fresnel lens, red
 53*g* Fresnel lens, green
 53*b* Fresnel lens, blue
 54*c* component wavelength beam
 54*d* component wavelength beam
 54*r* component wavelength beam, red
 54*g* component wavelength beam, green
 54*b* component wavelength beam, blue
 56*r* analyzer, red
 56*g* analyzer, green
 56*b* analyzer, blue
 60 modulator panel
 60*c* modulator panel
 60*d* modulator panel

62 projection lens
 62*c* projection lens
 62*d* projection lens
 62*r* projection lens, red
 5 62*g* projection lens, green
 62*b* projection lens, blue
 63*r* lens, red
 63*g* lens, green
 63*b* lens, blue
 10 64 image
 66 polarized illumination beam
 68 illumination section
 70 display surface
 74 polarizer
 15 76 uniformized polarized beam
 78 color separator
 80*r* red component modulating section
 80*g* green component modulating section
 80*b* blue component modulating section
 20 82*r* border portion, red
 82*g* border portion, green
 82*b* border portion, blue
 84*a* light blocking segment
 84*b* light blocking segment
 25 90*a* dichroic surface
 90*b* dichroic surface
 92 turning mirror
 94 half wave plate
 96 polarizer
 30 98 mirror
 100 control loop
 102*r* actuator, red
 102*g* actuator, green
 102*b* actuator, blue
 35 104 sensor
 106 target
 108 control logic processor
 110 polarized light providing apparatus
 114*r* component wavelength modulating section, red
 40 114*g* component wavelength modulating section, green
 114*b* component wavelength modulating section, blue
 116 shutter
 118 LC modulator panel
 120 LC material
 45 122 thin-film transistor (TFT)
 124 ITO layer
 126 glass
 128 polarizer
 130 compensation film
 50 132 color filter array
 134 antireflection coating
 136 antireflection coating
 140 color scrolling element
 140*c* color scrolling element
 55 140*d* color scrolling element
 142 line
 146 intermediate image
 148 polarization beamsplitter
 60 148*r* polarization beamsplitter, red
 148*g* polarization beamsplitter, green
 148*b* polarization beamsplitter, blue
 150 V-prism assembly
 152 mirror
 65 154 analyzer
 156 Fresnel lens
 200 projection apparatus

The invention claimed is:

1. A projection apparatus comprising:

a) an illumination section comprising:

- i) a first light source for providing a first illumination beam;
- ii) a second light source for providing a second illumination beam;
- iii) a third light source for providing a third illumination beam;

b) first, second, and third component wavelength modulating sections, each component wavelength modulating section accepting the corresponding first, second, or third wavelength illumination and modulating the corresponding wavelength illumination to provide a first, second, or third modulated component wavelength beam respectively, each component wavelength modulating section comprising:

- i) a portion of a monochrome transmissive liquid crystal modulator panel that has been segmented into at least a first portion, a second portion, and a third portion, and wherein each portion is spatially separated from each other portion;
- ii) a component wavelength polarizer in the path of the component wavelength illumination for directing substantially polarized light to the corresponding portion of the monochrome transmissive liquid crystal modulator panel;
- iii) an illumination path Fresnel lens for focusing incident illumination from the component wavelength polarizer through the corresponding portion of the monochrome transmissive liquid crystal modulator panel;
- iv) an analyzer for conditioning the polarization of the modulated component wavelength beam;
- v) a lens for forming an image for projection onto a display surface; and

whereby the image formed on the display surface comprises a plurality of superimposed component wavelength beams.

2. A projection apparatus according to claim 1 wherein the light source is a laser.

3. A projection apparatus according to claim 1 wherein the light source is a light emitting diode (LED).

4. A projection apparatus according to claim 1 wherein the transmissive liquid crystal modulator comprises thin film transistors.

5. A projection apparatus according to claim 1 wherein at least one component wavelength polarizer is spaced apart from the monochrome transmissive liquid crystal modulator panel.

6. A projection apparatus according to claim 1 wherein at least one analyzer is a wire grid polarizer device.

7. A projection apparatus according to claim 6 wherein the thin film transistors are organic thin film transistors.

8. A projection apparatus according to claim 6 wherein the thin film transistors comprise carbon nanotubes.

9. A projection apparatus according to claim 6 wherein the wire surface side of the wire grid polarizer device is oriented toward the liquid crystal modulator panel.

10. A projection apparatus according to claim 1 wherein at least one component wavelength polarizer is a wire grid polarizer device.

11. A projection apparatus according to claim 10 wherein the wire surface side of the wire grid polarizer device is oriented toward the liquid crystal modulator panel.

12. A projection apparatus according to claim 1 wherein at least one illumination path Fresnel lens is spaced apart from the monochrome transmissive liquid crystal modulator panel.

13. A projection apparatus according to claim 1 further comprising

- a) a sensor for detecting an offset between the plurality of superimposed component wavelength beams; and
- b) an imaging control processor for shifting the position of at least one of the first or second portions on the monochrome transmissive liquid crystal modulator to compensate for the offset.

14. A projection apparatus according to claim 1 further comprising

- a) a sensor for detecting an offset between the plurality of superimposed component wavelength beams; and
- b) an actuator coupled with at least one projection lens for adjusting lens position to compensate for the offset.

15. A projection apparatus according to claim 1 wherein at least one of the component wavelength modulating sections further comprises a modulated beam Fresnel lens.

16. A projection apparatus according to claim 15 wherein the modulated beam Fresnel lens is glass.

17. A projection apparatus according to claim 15 wherein the modulated beam Fresnel lens comprises crossed cylindrical Fresnel lenses.

18. A projection apparatus according to claim 1 wherein at least one of the component wavelength modulating sections further comprises a modulated beam Fresnel lens, wherein the modulated beam Fresnel lens comprises crossed cylindrical Fresnel lenses.

19. A projection apparatus according to claim 1 wherein at least one of the modulated beam Fresnel lenses is glass.

20. A projection apparatus according to claim 1 wherein the analyzer in at least one component wavelength modulating section comprises a wire grid polarization beamsplitter.

21. A projection apparatus according to claim 1 wherein the illumination section further comprises a shutter.

22. A projection apparatus according to claim 1 further comprising a compensator.

23. A projection apparatus according to claim 22 wherein the compensator is placed between the modulator panel and the at least one component wavelength polarizer.

24. A projection apparatus according to claim 22 wherein the compensator is a film-based component.

25. A projection apparatus according to claim 22 wherein the compensator is a multi-dielectric thin film stack based component.

26. A projection apparatus according to claim 22 wherein the compensator is in the path of the first component wavelength illumination.

27. A projection apparatus according to claim 22 wherein the compensator is in the path of a modulated component wavelength beam.

28. A projection apparatus according to claim 1 wherein the analyzer is spaced apart from the liquid crystal modulator panel.

29. A projection apparatus according to claim 1 wherein at least one analyzer is a reflective polarizing beamsplitter.

30. A projection apparatus according to claim 1 wherein the illumination path Fresnel lens is glass.

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31. A projection apparatus according to claim **22** wherein the compensator comprises a formed birefringent structure.

32. A projection apparatus according to claim **1** wherein the first, second, and third component wavelength modulating sections form an intermediate image for projection by a projection lens.

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33. A projection apparatus according to claim **1** wherein the monochrome transmissive liquid crystal modulator panel has a first antireflection coating on a first surface and a second antireflection coating on a second surface.

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